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RELATIONS OF NUISANCE ALGAE TO FISHES IN UPPER KLAMATH LAKE

Carl E. Bond, et al

Oregon State University

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Terminal Progress Report

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U.S. Federal Water Pollution Control Administration
Research Grant WP00625

OREGON STATE UNIVERSITY
Department of Fisheries and Wildlife - Agricultural Experiment Station

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April 1968

This progress report should be considered a manuscript and should not be cited as a publication.

ABSTRACT

1. Upper Klamath Lake is characterized as highly eutrophic with no summer thermal stratification. Usual summer temperatures are 20 to 22° C. Secchi disc readings are often as low as 1 foot, and often 99 percent of incident light is extinct at 2 to 3 feet, largely due to suspended Aphanizomenon and lesser amounts of other blue-green algae.

2. During winter, pH values of 6.7 to 8.0 were recorded. Summer pH usually ranged between 8.5 and 10.0. Alkalinity expressed as mg/l calcium carbonate ranged from 28.5 to 78.5. Dissolved oxygen ranged from 0 to 17.3 mg/l with most observations in the 6 to 13 mg/l range. Anoxic conditions were usually confined to bays and occurred during decomposition of large amounts of algae. Bottom sediments were shown to have a high oxygen demand.

3. Nutrient materials in bottom sediments are made available to the water mass almost daily during the ice-free period because of resuspension of bottom sediments. Wind velocities of from two to five mph can cause sufficient water movement to keep some bottom materials in flux.

4. Bottom materials near shore may consist of sand to boulders in exposed locations, or peat to plant detritus in bays or near swamps. Most lake sediments are brown to black, flocculent, and have a high organic content. Vascular plant fibers and diatom frustules are common features.

5. From May to October, Upper Klamath Lake is characterized by an abundance of Aphanizomenon flos-aquae. Gloeotrichia, Anabaena and Anacystis are represented but usually make up collectively less than 10 percent of the phytoplankton. Marshes and areas along the north shore of the lake tend to have lower concentrations of algae than other parts of the lake.

6. Cladocerans were the most abundant elements of the zooplankton. Average numbers of Daphnia per 10-liter plankton trap samples (8 to 14 samples in each zone) ranged from 88 to 296. Averages for copepod ranged from 76 to 124.

7. Earthworms (Oligochaeta) comprised the largest element of the benthic fauna, both in numbers and biomass. Leeches (Hirudinea) and midges (Tendipedidae) were second and third in rank. The summer population of midge larvae was estimated at about 440 billion (600 tons), which is about 100 billion less than previous workers estimated in 1932.

Most of the sediments underlying the open lake are occupied by an oligochaet-leech community, with relatively fewer midges, snails and clams. Near shore and in marshes, in coarser sediments midges, snails, clams, caddisflies and other aquatic insects become more numerous.

8. Blue chubs and tui chubs comprised over 90 percent of the catch of fish in 18,292 hours of fishing gill nets and trap nets. Twelve additional species made up the remainder. Distribution of chubs was apparently restricted

only by nearly anoxic conditions, although there appeared to be specific preferences for certain habitats.

9. Game and panfish (trout, yellow perch and brown bullheads) showed seasonal movements apparently related to heavy algal blooms with attendant fluctuations of dissolved oxygen, pH and suspended and dissolved materials. These fishes were usually found primarily in the north end of the lake during summer, or in other areas affected by incoming water. Live-boxed trout failed to survive the combination of high pH, moderate temperature and fluctuating dissolved oxygen at the south end of the lake.

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INTRODUCTION

The research covered in this report was conducted during the period June 1, 1964 to May 31, 1967 under grant number WP00625. The purpose was to discover, describe, and if possible, quantify the relationships between blue-green algae and the fishes of Upper Klamath Lake. Recognition of these relationships should have predictive value in dealing with similar shallow bodies of water, or with impoundments which might receive water from Upper Klamath Lake.

Attention was given to direct effects through a program of sampling the fish population, and to indirect influences through study of the benthic community upon which the fish depend for food. Aspects of the limnology basic to the objective were investigated.

STUDY AREA

Upper Klamath Lake is located in south central Oregon at the eastern edge of the Cascade Mountains (Figure 1). It has a surface area of about 154 square miles in a basin of 7450 square miles, and is at an elevation of 4143 feet.

According to Smith and Greenup (1939) Upper Klamath Lake is of rather recent origin and the only tectonic basin in the region having external drainage. In Hutchinson's (1957) classification of lakes, it is type 9, a fault block basin enclosed on both sides by infacing escarpments.

The basin contains an interconnected series of marshes, streams, and lakes all draining toward Upper Klamath Lake. Drainage from the lake is by way of Klamath River 236 miles to the ocean. Major tributaries to the lake are Williamson River, Wood River, and Seven Mile Canal. These have annual flow ranges of approximately 500-2000 cfs, 200-500 cfs, and 70-200 cfs, respectively.

Figure 2 is a bathymetric map of the lake redrawn from one made by the U. S. Bureau of Reclamation in 1953. Depths are at maximum surface elevation and may be two to four feet less during autumn and winter.

The basin is sparsely populated. Chiloquin is the largest community with a population of 950. Most of the villages, such as Bly, Beatty, Fort Klamath, etc., have 50 to 150 people. Domestic wastes from these communities are at least partially treated (Oregon Sanitary Authority, 1964), the major portion of the man-related nutrient load entering local streams originates primarily from agriculture. Additional organic matter entering the lake may come from 212 square miles of marsh

and 144 square miles of irrigated peat land. Miller and Tash (1967) estimate that 20 percent of the nitrogen, and 26 percent of the phosphorus entering the lake is from agricultural sources.

From about 1850 to the present, logging, ranching and tourism have been primary industries in the basin.

According to research done by Devere Helfrich (1965) of Klamath Falls, the first documented entry of white men into Klamath Basin was in 1825 by the McDonald-McKay-Hudson Bay Company party. Although other white men had passed through the area, it was Capt. John C. Fremont who left the first authenic written record of seeing and using boats on the lake about 1846. These boats were the dug-out canoes of Modoc Indians. After 1865, Upper Klamath Lake was a major trade route in the basin. A 65 foot streamboat, the General Howard, went into service on the lake in 1882. The last large boat of commercial importance on the lake was the three-decked sternwheeler, Winema, which was operated from 1905 to 1919. It was displaced by railroads and highways.

Since 1917, when a Bureau of Reclamation dam was constructed, waters of the lake have been used extensively for irrigation, power, and recreation. Hunting during season is available for several species of game. Fishing is for trophy-sized rainbow trout, which may exceed 25 pounds. Eagles and ospreys are a common sight; pelicans and other water birds and shore-birds are numerous, and many species of small birds and mammals frequent the lake shores.

CLIMATE

About 80 percent of the time mean annual precipitation has ranged between 9.50 and 17.00 inches with 50 year extremes of 8.31 and 20.91. Most of this

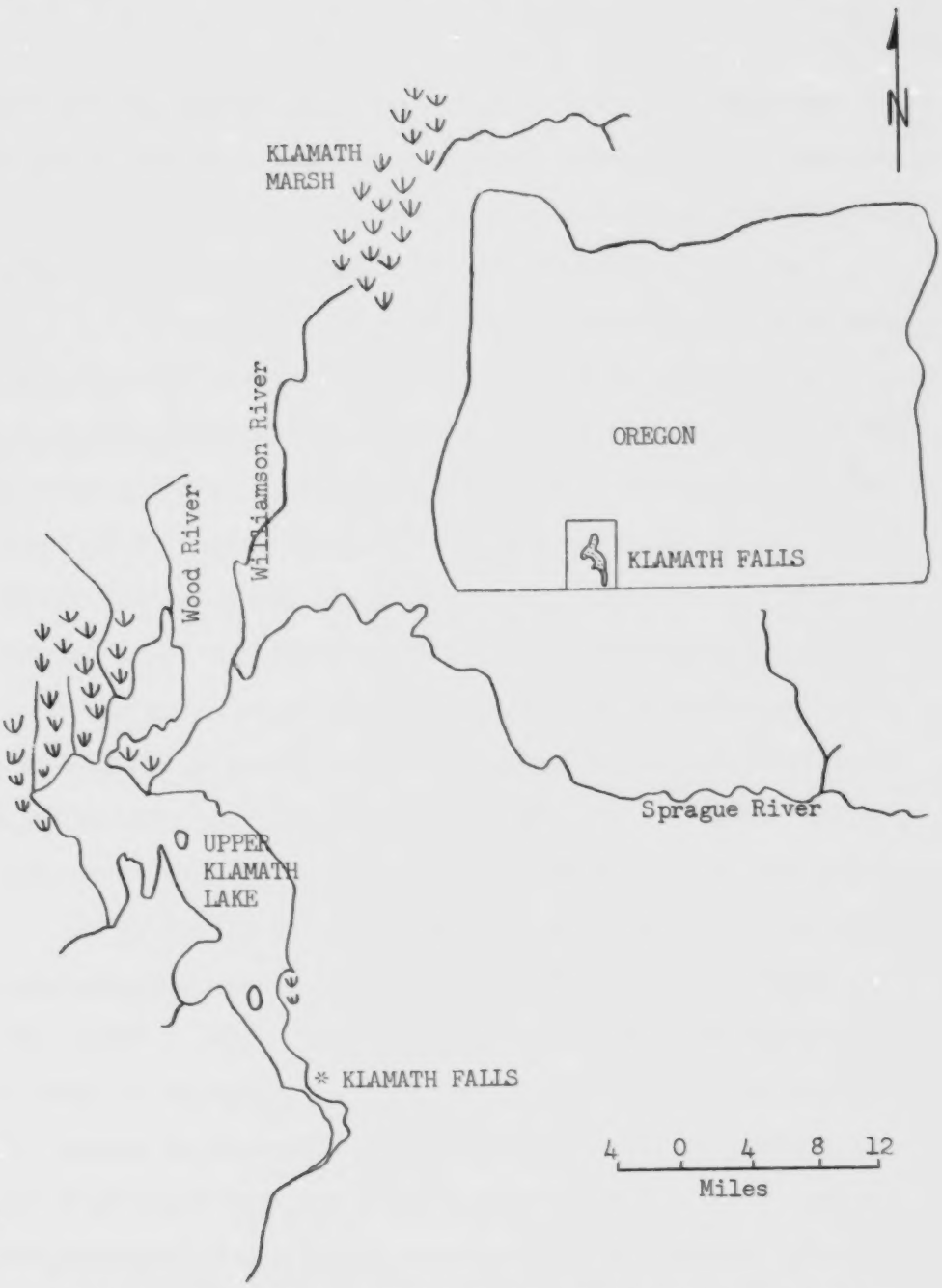

Figure 1. Vicinity of Upper Klamath Lake showing the location of major tributaries.

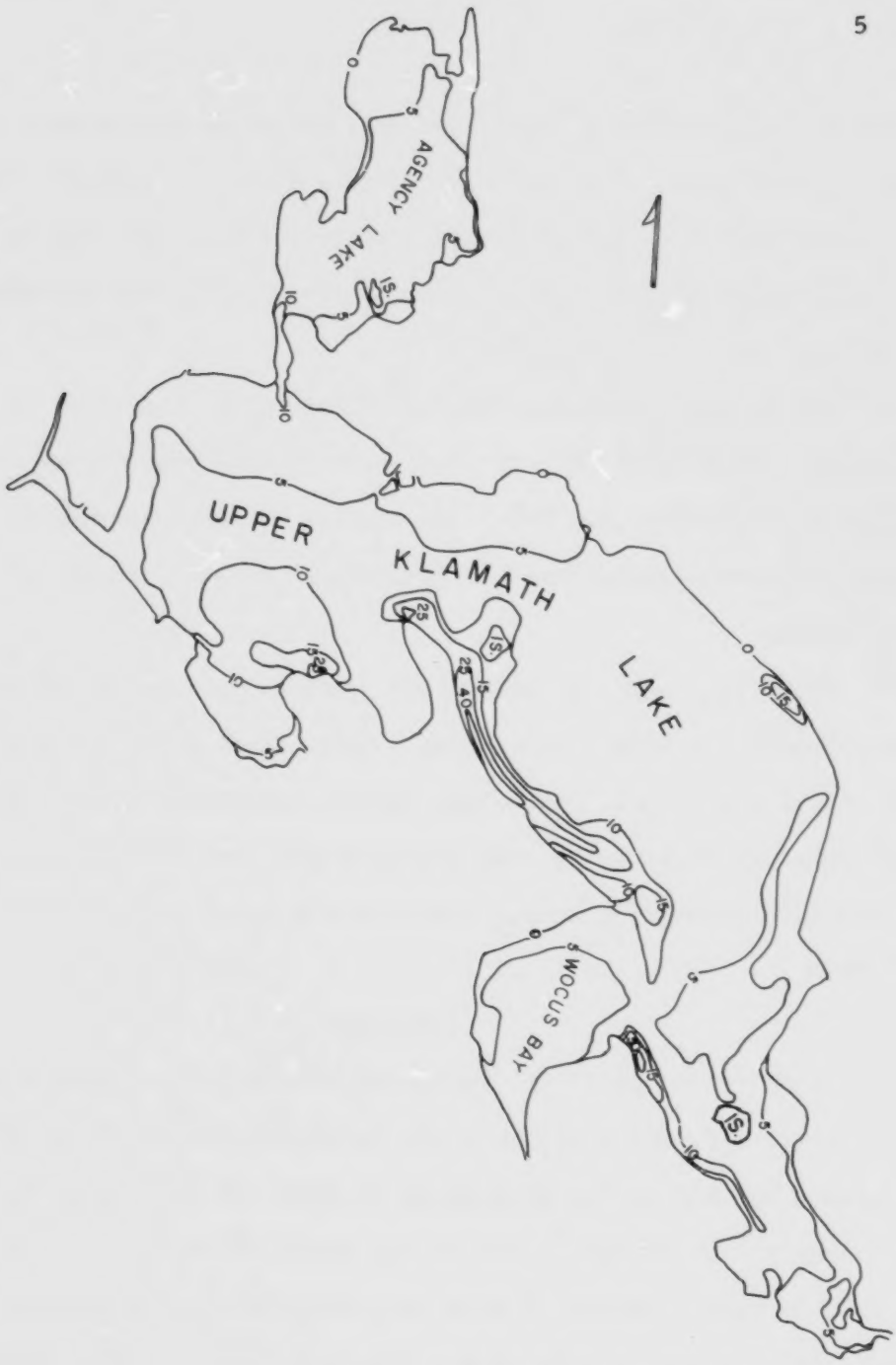

Figure 2. Bathymetric Map, Upper Klamath Lake.

precipitation, approximately 70 percent, occurs as snow between October and March. There are occasional thunderstorms during the summer. The sun may shine as much as 90 percent of the time during July, and only in January does it shine as little as 33 percent. From June through September overcast days are rare.

The 50 year extremes in temperature are from minus 16°F to 105°F; however, for at least half of these years extreme temperatures were above zero and less than 96°F. The average relative humidity is less than 50 percent except from November through February when it is 53 to 76 percent.

Prevailing winds on the lake are southerly during the wet season and northerly at other times. They average about 5 m.p.h. but frequently exceed 15 m.p.h. (U.S. Dept. Comm. Weather Bureau, Klamath Falls, Oregon). The lake may become quite rough during storms, and over the years several boats have capsized in strong winds and high waves.

METHODS

Limnology

Dissolved oxygen (D.O.) was determined using the Pomeroy-Kirschman-Alsterberg azide modification of the Winkler Method, as suggested in Standard Methods for the Examination of Water and Wastewater, 11th Edition, for waters high in organic content and where concentrations of D.O. may exceed 15 mg/l. Samples of water were collected with a Kemmerer bottle and fixed through the acid stage. They were held in closed containers until evening when they were titrated with 0.025N phenylarsene oxide (PAO) purchased from the Hach Chemical Company.

Alkalinity was determined using standard methods with methyl orange indicator.

Hydrogen ion activity was estimated with a battery-operated pH meter manufactured by Summit Instrument Company of New Jersey. This meter has a reported accuracy of 0.1 pH; however, we experienced considerable difficulty obtaining measurements within $\pm$ 0.2 pH in comparison tests with a Beckman Model G meter.

Temperatures were taken with a thermistor type therometer.

Extinction coefficients of visible light were estimated from data obtained using a submarine photometer manufactured by the G. M. Manufacturing Company. Light penetration data was taken only on clear days and in calm water. Measurements were made at intervals of 0.5 feet.

The abundance of seston, retained by a cone-type plankton net of special design and constructed of Number 25 bolting cloth (nylon) was used as an index to the concentration of Aphanizomenon in the lake (Figure 3). This net was cast from a boat and allowed to sink, and then a nearly vertical 10 foot tow was made. With an opening of six inches diameter the net theoretically filtered 54 liters. After being brought aboard it was hung vertically and excess water drained from the sample. While still in the tube samples were smoothed to a thickness of $\frac{1}{4}$ inch and amounts of residue were measured and recorded in inches. Two such tows were made, and the average of the two were used to represent the abundance of seston. Reproducibility of results was checked by comparisons of inches measured with dry weight of the sample.

Zooplankton were collected with a Juday Plankton Trap using Number 12 nylon netting except during the fall when a Number 12 cone-type net was used. Zooplankton were preserved in 5 percent formalin or 70 percent ethanol until identified and counted.

Benthos samples were taken with an Ekman dredge. Organisms were separated by washing sediments through a U. S. Number 32 sieve. The retained residue was preserved in 70 percent alcohol until hand-picked. Samples were collected by hand in rocky areas and from marsh plants.

Studies of concentrations of D.O. near the bottom, the settling flux of seston, and substrate preferences of benthic invertebrates required special techniques and materials which are described in individual sections of this report.

The locations where samples were taken were either chosen randomly, by throwing a die to fix a position, or at stations selected for continuous study. Using information obtained from collections made during preliminary investigations carried out in 1964, the lake was divided into three zones (I-south end, II-middle, III-north end). Each zone was divided into three parts and then bisected. Each bisected zone was further divided into six nearly equal area. A number, one through six, was assigned to each of these areas with odd numbers on the westerly side. Each area was subdivided again into three sections of equal size in relation to shore line length and designated by a letter, either a,b, or c (Figure 4). Stations selected for special experiments are shown in the figure by a star. Schematic sketches of the four standard stations are in Figure 5.

FISH

Gill nets and hoop nets were used in an exploratory survey of fish distribution in 1964. Possible seasonal and spatial differences in distribution were indicated by the preliminary investigation, and a sampling program, randomized in relation to three shoreline habitats, away from the direct influence of incoming waters, was developed for use in 1965. Fish and basic limnological conditions were sampled monthly

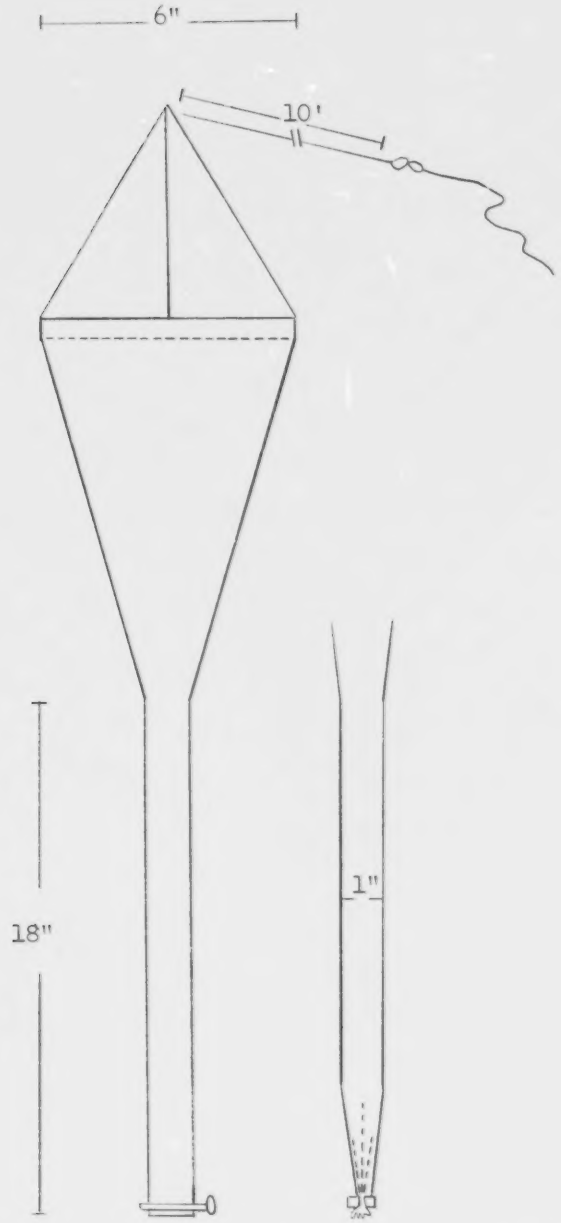

Figure 3. Cone type net used to estimate the concentration of net seston in inches.

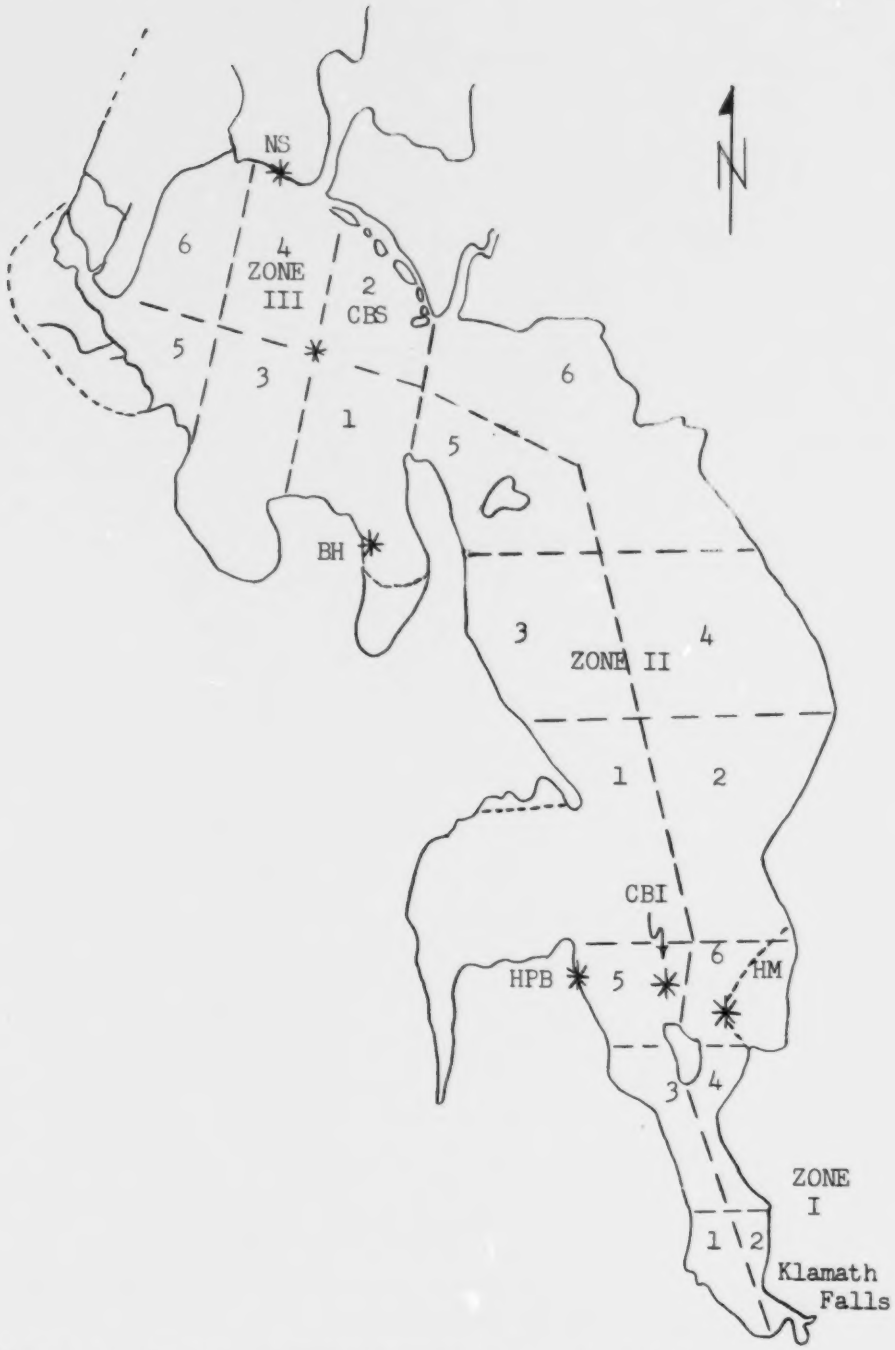

Figure 4. Sketch of Upper Klamath Lake showing Zones, Areas, and Sections, and the Standard Sampling Stations.

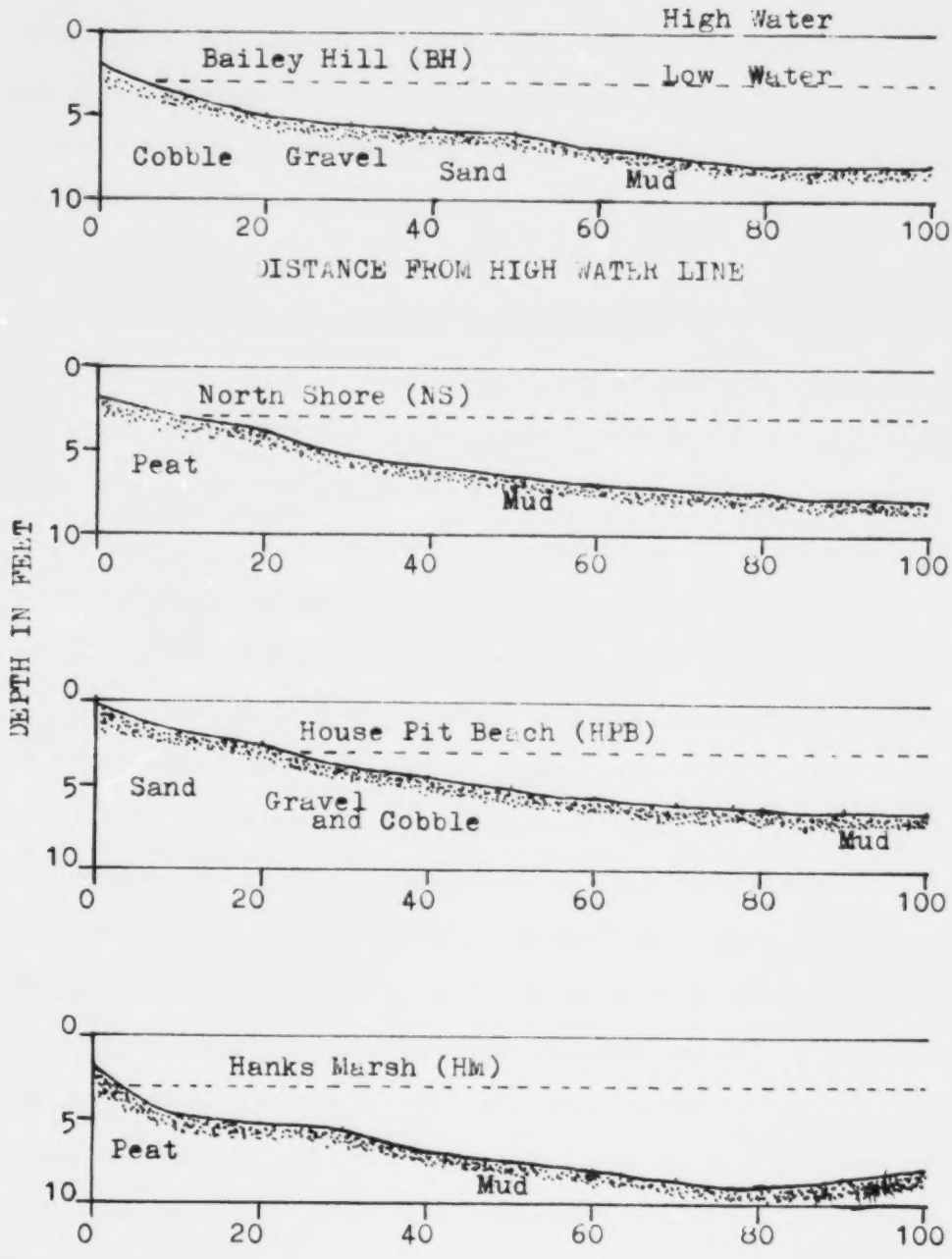

Figure 5. Depth profiles of Standard Stations with nota-
of sediment types.

(excluding October) throughout the summer and fall.

Fish sampling was done with two sets of nets, and the results of each set in a zone were added and treated as one unit for analysis. All fish were removed from the gill nets as the nets were brought into the boat. The numbers of fish in each type of net and mesh size in which they were caught were recorded. In order to compare magnitudes of monthly catches these data were converted to percentage of the catch for each zone during a particular month of sampling. Percentages were used in place of fish per hour for comparison among the different sampling periods in order to minimize sampling bias due to possible extraneous influences on the activity of the fish.

Each set of nets consisted of one 7 x 100-foot floating gill net; one 5 x 50-foot floating gill net; one 7 x 100-foot diving gill net and one 5 foot circular hoop net. Stretched mesh sizes were 1 1/4, 1 3/4 and 3 inches for the three-panel floating nets and 1 1/4, 1 3/4, 2 1/4, 3 and 6 inches for the five-panel diving gill nets.

To minimize sampling error a definite pattern was followed for placement of nets. The 50-foot floating gill net (net #1) was set parallel to and 10 to 15 yards offshore; the 100-foot floating gill net (net #2) was set perpendicular to the shore beginning not more than 5 yards from the waters edge; the 100-foot diving gill net (net #3) was set perpendicular to shore in line with net #2. The hoopnet was set parallel to and in most cases within 10 yards of the shoreline. The above pattern was followed regardless of the shoreline habitat sampled.

Sampling Procedure, Rocky Shoreline. To determine where the two sets of nets would be placed in each zone during the sampling period, a die was rolled twice for the placement of each set; the first number determined the area (one through six); the second established the section -- (numbers on the die were assigned so they could be interpreted as a, b, or c; e.g., one or two as a; three or four as b; five or six as c). After the die was rolled twice an example of the result or the area and section placement of the set would be as follows; I - (zone), 4 - (area), c - (section). If the number on the die duplicated a section or indicated an area not having a rock shoreline, the number was rejected and the die rolled again. Sampling started at Zone I and proceeded to Zones II and III and then returned to Zone I. In this manner three cycles of samples were established for each nine-day sampling period.

Sampling Procedure, Marsh Shoreline. Four marsh shoreline areas were selected for sampling in July, September and November of 1965 (Figure 6). The procedure was virtually the same in determining placement of the two sets of nets as for the rocky shoreline. The marsh areas were divided in half, in relation to shoreline length, and each half was designated a or b. In order to randomize the sampling, numbers on the die were assigned to be interpreted as a or b and the die was rolled only once to determine in which section the nets would be placed. On the first and third days of the four-day sampling period, one set of nets was placed in each of the southern marsh areas (Hanks and Wocus marshes); then on the second and fourth days the nets were moved to the sections of the two northern marshes (Shoalwater and North marshes) as determined by the roll of the die.

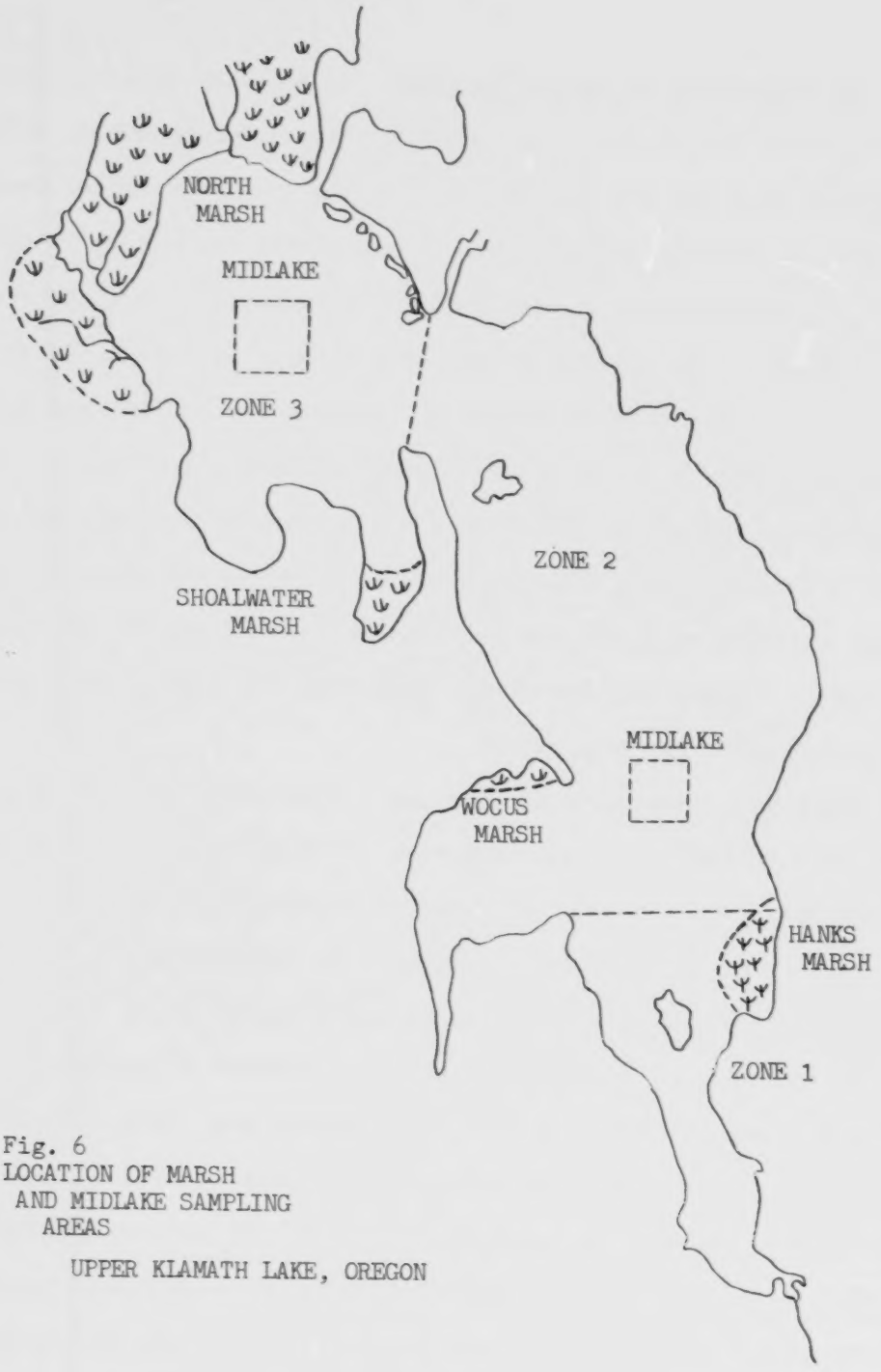

Fig. 6
LOCATION OF MARSH
AND MIDLAKE SAMPLING
AREAS

UPPER KLAMATH LAKE, OREGON

Sampling Procedure, Midlake. Areas in the middle of the lake within Zones II and III (Figure 4) were selected for sampling of fish away from the influence of the shoreline. One set of nets was placed in each area simultaneously. Nets were fished and replaced each day for the four-day sampling period in August and the two-day sampling period in September. The lake surface froze early in December before another sample could be taken.

Statistical Procedures. Environmental factors were measured when the nets were placed into the water and again when they were removed. Consequently, two sets of data required analysis in order to determine any possible effect on the distribution of fishes.

A correlation matrix, utilizing 31 variables, was designed to run on an IBM 1410 computer. Results indicated that still further elimination of variables was necessary, consequently a step-wise regression analysis was utilized to narrow the number of variables to about ten.

A step-wise regression analysis is an extension of the correlated variation principle as discussed by Overton and Florshutz (1962) in which they state: "It is then a simple extension of these ideas (correlated variation) to examine the variability left in Y after accounting for that associated with X_1 (variable one), to see if any of this remaining variation can be associated with a second variable, X_2." In this manner all measured variables were taken into consideration and each variable entered in order into the regression analysis according to its contribution to the variation of Y (F value). The results were then printed in a ranked descending order of contributing variables.

RESULTS

LIMNOLOGY

There is very little published information on the aquatic biology of Upper Klamath Lake. Near the turn of the century many of the great ichthyologists visited and reported on species of fish in the lake (Gilbert (1898), Cope (1883), Snyder (1908), Evermann and Meek (1898).

A party investigating biological and chemical characteristics of Northwestern lakes worked at Klamath on July 29, 1913 (Kemmerer _et al._, 1924). Their impression of the lake, as quoted below generally remains valid today.

> "The lake is noted for its rainbow trout (_Salmo irideus_) fishing, which, considering the warm water...and the abundant growth of algae, appeared interesting. Two trout that weighed from 4 to 5 pounds each were caught near Eagle Ridge. They took a small spoon readily (they would not take a fly, but were reported doing so earlier in the season) and fought well. The flesh seemed hard and firm, but when cooked it had a very marked weedy taste similar to the trout from Henry Lake, Idaho. The best fishing was reported at the mouth of streams where the cooler water occurred.
>
> Because of the shallowness of the lake, the phyto-plankton flourishes and tends to decrease very materially the transparency of the water. The Secchi disk disappeared from view at a depth of less than 1 M. The lake was so shallow that the waves kept the water in circulation from

top to bottom, and no thermocline had formed."

Kemmerer's party was at the lake before the Bureau of Reclamation dam was constructed, thus it may have been shallower then than now. Since 1913 there has been a change in the dominant species of plankton.

Secchi disc readings during the present study were usually less than 0.5 meter during July, and the average July surface water temperatures were above 70 which is considerably greater than the 59°F recorded in 1913. In addition, trout fishing near Eagle Ridge in recent years has been nonexistent or marginal during July.

Davis, Jewett, and Mote (1938) investigated the biology of Klamath midges (Chironomus) which were a serious nuisance during the 1930's. Their report, which also includes information gathered by Dimick on fish in the lake, is an unpublished report on file in the O.S.U. Department of Entomology. Bonnell and Mote (1942) using information from the previously cited report described some features of the biology of a midge (Chironomus utahensis) resident in the lake. They brought out in their study that Aphanizomenon was abundant and cited a maximum of $20X10^6$ filaments per cubic meter.

Aphanizomenon concentrations were observed to be as high as 194,756 per ml by Phinney and Peek (1961). If this number per ml is magnified to number per cubic meter in order to compare it to the previously listed $20X10^6$ per cubic meter, it is about 10,000 times as great. Although this comparison is not to be considered accurate in any sense, it does represent the thesis that the concentration of Aphanizomenon has increased greatly over the last 50 years, and it is also supported by conversations with older residents who recall conditions in the lake previous to about 1917.

The level of the original lake was raised about six feet with the construction of a dam in 1917 by the Bureau of Reclamation. It is now

operated by the Pacific Power and Light Company. In addition to diversion for power, which flows parallel to Link River, irrigation water is diverted through "A" Canal into the Lost River drainage (Orlob and Woods, 1964). A fish ladder allows fish to migrate upstream over the dam; however, both irrigation and power diversions lack fish-screens. The combined outflow from the lake ranges from about 1400 to 2500 cfs.

Temperature

Surface temperatures during the year vary from 0°C (32°F) to 24°C (75°F). The lake freezes over about the first of the year and thaws in late February or early March. Temperatures are above 10°C from April to November, and above 15°C from May through September. During the warmest period of July and August, the usual temperatures are 20 to 22°C.

There is no thermocline. When there was little wind activity there were temperature differences between surface and bottom (depths of two to three meters) of 1 to 2°C. Measurements of temperatures during July and August, 1966, at six standard stations are given in Table I.

Light Penetration

For purposes of comparisons within the lake, extinction coefficients (K) were calculated for subsurface light measurements at depths of one and three feet, using a formula modified from Sverdrup, Johnson and Fleming (1942).

$$K = 2.3 \frac{(\text{Log } I_1 - \text{Log } I_3)}{0.609 \text{ meters}}$$

During the period of March 21 through September 30, 1965, K values ranged

Table I. Temperatures at standard sampling stations during July and August, 1966, Upper Klamath Lake.

DATE / DEPTH	7/6	7/12	7/15	7/19	7/21	7/27	8/4	8/9	8/12	8/17	8/20	8/24	8/31
HOUSEPIT BEACH (HPB)													
S	64.8	67.1	68.0	66.5	72.0	69.0	70.2	68.0	69.2	72.2	73.2	69.2	65.5
2	64.0	67.1	67.5	65.5	70.2	67.8	70.2	68.0	69.0	72.0	72.8	68.5	66.2
4	64.0	65.0	64.0	65.0	69.8	67.0	69.8	68.0	68.5	71.8	72.5	68.5	65.5
6	63.9	64.0	62.5	64.5	68.5	66.0	69.5	68.0	68.2	71.5	72.0	68.2	65.0
8	63.9	64.1	62.0	64.1	68.2	66.0	69.2	68.0	68.0	71.5	72.0	68.0	65.0
10	64.0	64.2		64.0		65.5	69.2						
12	64.0					66.0							
CENTER - ZONE I													
S		64.5	67.2		72.2	68.0	70.0	68.2	69.0	71.0	73.5	69.2	66.8
2		64.5	67.0		71.0	67.2	69.9	68.0	69.0	70.5	73.2	68.8	65.5
4		65.0	66.0		71.0	66.0	69.5	67.5	68.5	69.8	72.5	68.5	66.2
6		63.0	66.0		69.0	65.8	69.0	65.0	68.2	69.5	72.2	68.2	64.5
8		63.0	63.0		68.5	65.5	69.0	65.0	68.0	69.2	71.5	67.5	64.0
10			63.2		68.2	65.5					71.2	67.2	64.0
12													

Table I. Cont.

DATE	7/6	7/12	7/15	7/19	7/21	7/27	8/4	8/9	8/12	8/17	8/20	8/24	8/31
DEPTH													
	HANKS MARSH (H.M.)												
S		65.5		68.0	72.2	67.5	71.0	67.5	69.5	71.8	72.5	67.0	65.5
2		65.0		67.5	71.0	65.5	70.2	66.0	69.5	70.2	72.2	67.2	65.2
4		64.8		67.0	71.0	64.8	70.0	65.2	69.2	69.8	71.8	67.5	65.0
6		64.5		66.0	69.0	64.5	69.8	64.8	68.5	69.5	71.5	67.0	65.0
8		64.0		65.8	68.5	64.0	69.5	64.8	68.2	69.5	71.2	67.0	
10					68.2								

DATE	7/6	7/12	7/15	7/21	7/28	8/11	8/12	8/19	8/21	8/23
	BAILEY HILL (B.H.)									
S	66.0	65.0	63.0	75.0	72.5	69.2	70.5	74.0	72.5	69.5
2	65.8	65.0	63.0	72.5	70.5	69.0	70.5	73.5	72.2	69.2
4	63.5	64.2	62.5	67.2	70.0	68.0	70.2	71.0	72.2	68.5
6	63.0	64.0	62.0	65.2	69.8	67.8	69.5	70.0	71.8	68.2
			62.0	65.0			69.2	69.8		68.2
8		64.0				67.5			71.5	
10										
12										

Table I. Cont.

DATE	7/6	7/12	7/15	7/21	7/28	8/11	8/12	8/19	8/21	8/23
DEPTH										
	CENTER - ZONE III									
S		62.0	63.2	72.0		70.2	69.0	74.2	73.5	69.5
2		62.5	63.0	69.0		70.0	68.5	73.8	73.2	69.5
4		62.0	61.5	67.5		69.0	67.0	72.0	72.8	69.2
6		62.0	61.0	65.5		68.5	66.8	71.5	72.5	68.2
8		61.5	60.0			68.2	66.5		72.2	68.0
									72.0	68.0
10		60.0	59.8			68.0				
		60.0								
12										
	NORTH SHORE (N.S.)									
S		6.0	6.8	72.0		68.5	67.0	73.2	72.2	69.5
2		60.5	61.5	71.0		68.2	67.0	72.5	72.0	69.8
4		59.5	61.0	69.8		68.0	66.5	72.2	72.0	69.5
6		59.0	59.0	69.2		67.0	66.2	70.0	71.8	69.2
				69.0				69.8	71.5	
8			59.0			67.0	66.0			68.5
						67.0	66.0			
10										
12										

from 1.32 to 11.56 and were usually from 2.0 to 3.0. Similar values were observed in waters of the Sacramento - San Joaquin Delta by Charles Seeley (personal communication). In Klamath Lake, the depth at which 1 percent of the surface light remained was often 2 to 3 feet. Reid (1961) mentions a range of depths for western Lake Erie of 3.9 to 25 feet.

The observed extinction coefficients along with Secchi disc and inches of net-seston are given in Table II.

Gross differences in K between zones and areas were not evident except for those observations made at the North Shore Station (N.S.). On only two occasions were K factors determined for all three zones during the same day, March 23, and June 28 (Table III). Although K was similar in value on those two days, the form of turbidity was quite different. On March 23 the lake was at a low level of depth, and much of the turbidity resulted from bottom sediments which had been suspended by wind action. On June 28 turbidity resulted from a dense growth of algae (Aphanizomenon).

The N.S. station had lower K factors than other stations. Both N.S. and Hanks Marsh (H.M.) stations are adjacent to large marshes and are used here to illustrate a difference. The K factors calculated for these two stations are shown in Table III. The average K at H. M. is almost twice that at N.S. This observed difference probably results from the source of water that moves through these stations.

Inside both marshes during the summer the water is relatively clear and Aphanizomenon is not present in large numbers, but in comparison, in the open lake adjacent to these marshes algae is extremely abundant. Water at H. M. station is in the main circulation pattern of open lake water and therefore contains abundant algae, while water at N.S. is to a large extent water that is flowing from the marsh into the lake. This flow of

Table II. Observations of net-seston in inches, Secchi disc in inches, and calculated extinction coefficients (K) in Upper Klamath Lake during 1965.

ZONE	DATE	TIME	NET-SESTON	SECCHI DISC	K
I	3/21	1220	-	27	2.40
I	3/21	1415	-	25	2.79
I	3/21	1500	-	26	2.56
II	3/22	1300	-	22	2.96
II	3/22	1200	-	-	2.89
II	3/22	1110	-	22	2.55
III	3/23	1000	-	21.5	3.29
III	3/23	1400	-	20.5	2.27
III	3/23	1430	-	-	2.17
I	6/28	1020	1.5	39	2.29
I	6/18	1030	1.75	42	2.54
I	6/28	1100	1.25	62	1.86
II	6/28	1245	1.25	48	2.10
II	6/28	1210	1.25	59	1.78
II	6/28	1150	2	44	2.51
III	6/28	1325	1.25	53	1.98
III	6/28	1350	2	43.5	2.61
III	6/28	1415	0.5	53	1.59
I	7/19	1100	2.25	-	2.31
I	7/19	0900	2.25	-	3.19
II	7/20	1030	0.5	-	2.66
III	7/21	1125	4	-	3.96
III	7/22	1100	T	-	1.41
III	7/22	1235	0.63	-	1.51
I	7/23	1200	3.13	-	2.63
I	7/23	1000	1.13	-	2.50
I	7/24	1200	1.5	-	3.02
II	7/24	1200	0.25	-	1.75
III	7/25	1030	1.25	-	2.84
I	7/26	1045	5.63	-	7.66
III	7/27	1400	0.88	-	2.06
III	7/27	1135	T	-	1.32
I	7/28	1045	1	-	2.50
I	7/28	0845	1.88	-	2.79
II	7/29	0930	2	-	2.90
II	7/29	1030	1.75	-	3.03
III	7/30	0900	7	-	7.22
III	7/30	1000	1.5	-	2.14
III	8/01	1440	T	-	1.70
III	8/03	0800	2.38	-	4.90
III	8/03	1200	2.75	-	3.07
I	8/04	0830	1.75	-	3.02
I	8/04	0930	3.25	-	4.01

Table II. Cont.

ZONE	DATE	TIME	NET-SESTON	SECCHI DISC	K
II	8/05	0845	2.13	-	3.02
II	8/05	1150	1.25	-	2.33
III	8/06	0900	4.25	-	5.03
III	8/06	1130	0.63	-	2.48
II	8/13	1100	6.13	-	7.85
III	8/13	0900	4.75	-	6.40
II	9/02	1030	4.75	-	3.87
II	9/02	1230	8.5	-	8.32
III	9/03	1130	1.5	-	2.88
III	9/03	1030	5	-	5.14
I	9/08	0830	2.5	-	3.88
I	9/08	1000	10.13	-	11.56
II	9/09	0830	3.5	-	2.52
III	9/10	1030	4.87	-	2.79
III	9/10	0430	3.5	-	4.39
I	9/11	1030	7.38	-	6.91
I	9/11	1200	8.75	-	6.31
III	9/14	1330	8.5	-	10.95
III	9/14	1230	1.5	-	4.16
II	9/29	1130	T	-	3.39
III	9/29	1100	10.25	-	4.30
III	9/30	1130	T	-	2.23

TABLE III. A- Values of K taken on two days at seven locations.
B- Observed values of K at Hanks Marsh (H.M.) and North Shore (N.S.) during 1965.

		HPB	CBI	HM	ER	BH	CBS	NS
A	3/23/65	2.40	2.79	2.56	2.89	3.70	2.27	2.17
	6/28/65	1.86	2.54	3.29	2.51	1.98	2.61	1.59
B	7/19/65			2.31				-
	7/19/65			3.19				-
	7/22/65			-				1.41
	7/22/65			-				1.51
	7/23/65			2.63				-
	7/23/65			2.50				-
	7/24/65			3.02				-
	7/26/65			7.66				-
	7/27/65			-				1.32
	8/01/65			-				1.70
	9/30/65			-				2.23
	MEAN	2.13	2.67	3.27	2.70	2.84	2.44	1.70

marsh water is especially evident during prolonged periods of northerly winds. With southerly winds, the water at N.S. may be more representative of open lake water, thus very turbid.

Seasonally, mean K may vary from about two to five. Lower values of K were observed during the spring and early summer increasing to maximum in August and September (Figure 7). During the period of May through October, light penetration is influenced primarily by the density of Aphanizomenon. Variations during other periods result from sediments stirred up by wind action and blooms of diatoms (Melosira, Navicula).

The relationship between K and the quantity of net-seston is shown in Figure 8. Although the net-seston contained considerable quantities of zooplankton and detritus, variations in K at values over about two were primarily the result of concentrations of Aphanizomenon.

Hydrogen Ion Activity

During 1965 and 1966, pH varied from near 7.0 to 10.0. Variation followed temperature and the bloom of Aphanizomenon with a low value of 6.7 on December 5, 1965, at North Shore and a high value of 10.0 on July 21, 1965, in Zone I. Generally pH was less than 8.0 from November through April, and greater than 9.0 during July and August. There was very little variation from surface to bottom. Inside marsh areas, pH varied from about 6.5 to 7.0 throughout the year.

Alkalinity

Alkalinity as mg/l calcium carbonate varied as follows: Zone I, 45.3 - 55.0; Zone II, 28.5 - 65.5; and Zone III, 45.0 - 78.5. There was some indication that alkalinity increased alightly throughout the summer.

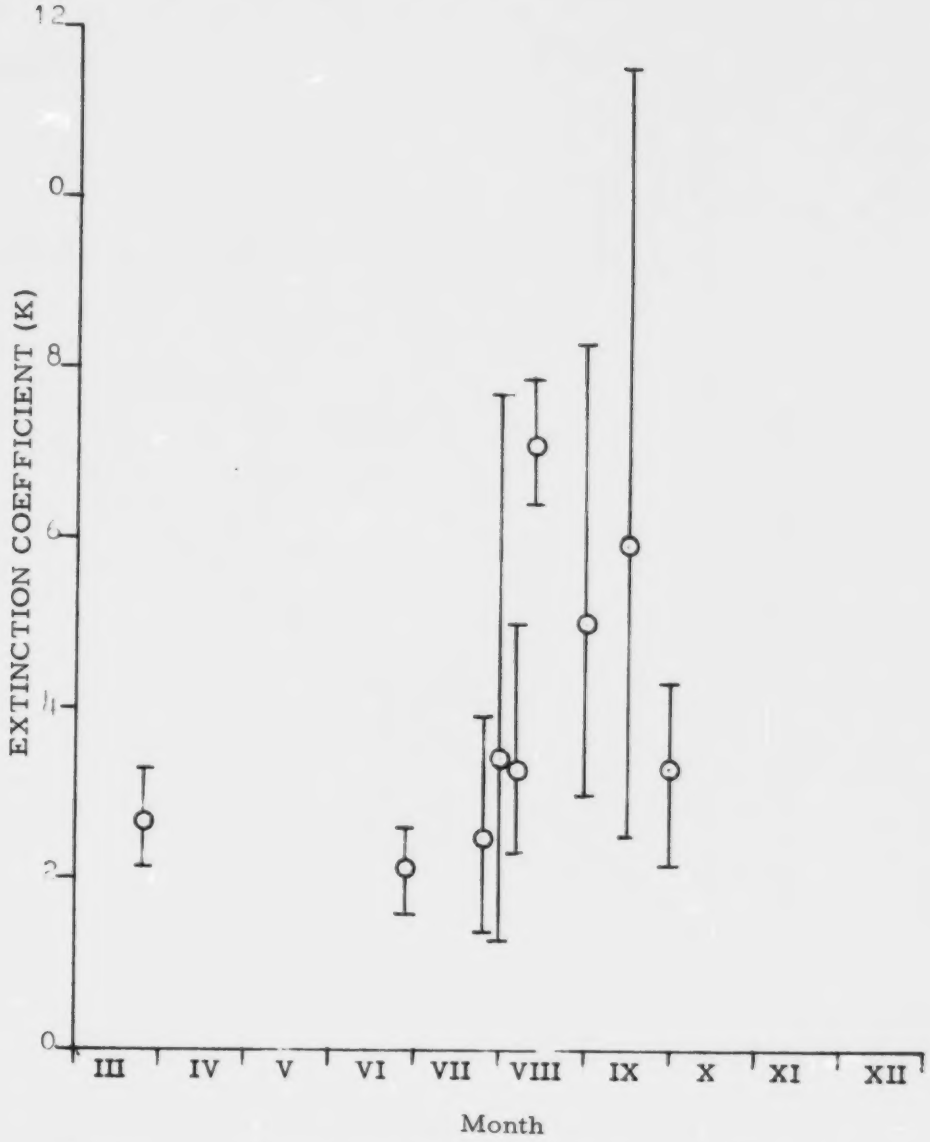

Figure 7. Seasonal variation in Extinction Coefficients (K).

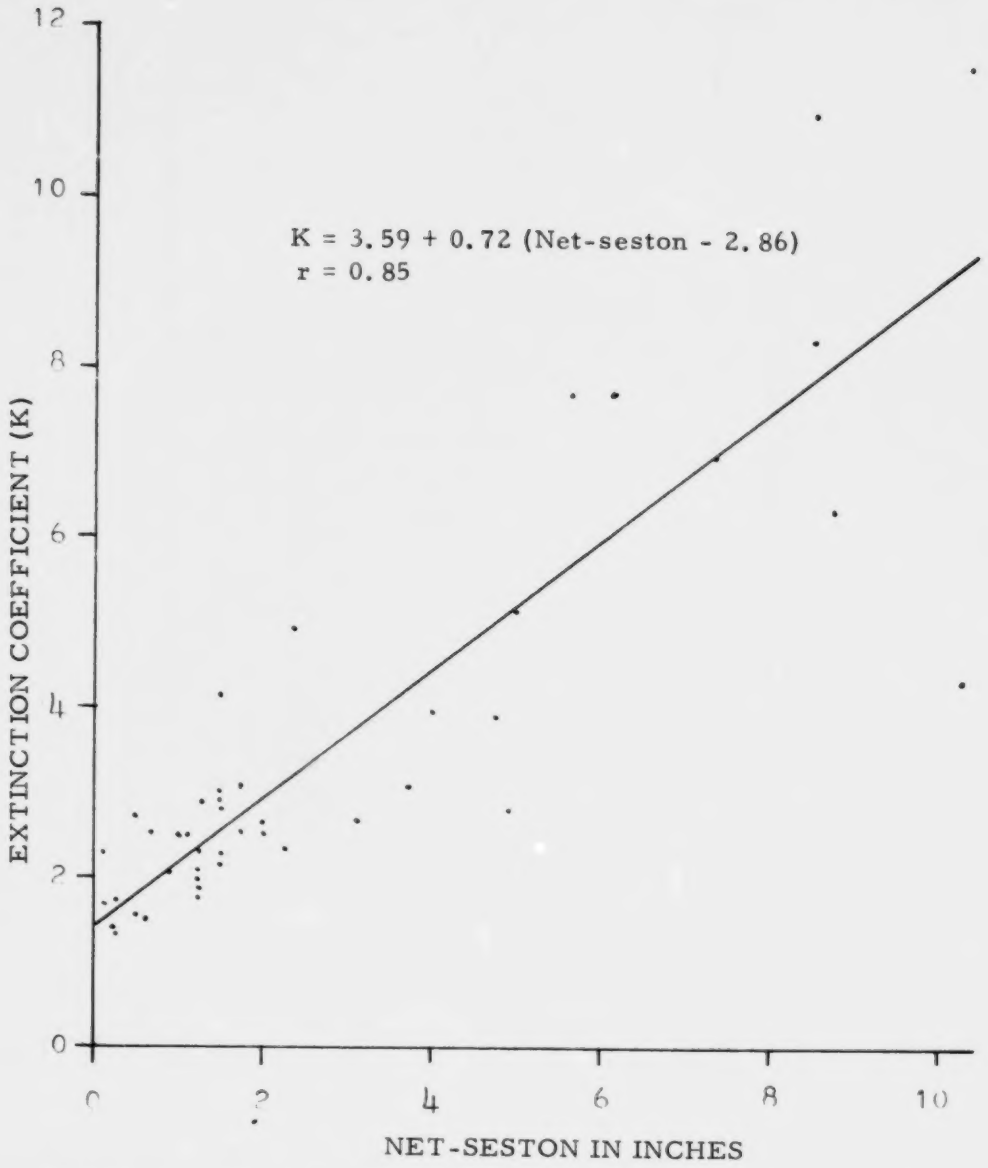

Figure 8. The relationship between Net-seston in inches and Extinction Coefficient (K).

Dissolved Oxygen

Dissolved oxygen was observed in Klamath Lake over periods of time between March 1965 and December 1966. Concentrations of dissolved oxygen were found to range from near 0 to 17.3 mg/l, with most observed concentrations between 6 and 13 mg/l. In Table IV is a list of low concentrations that were thought to be detrimental to ecological stability within the lake. Most of these observations were made in Howard and Shoalwater bays which were anaerobic on several occasions. In regard to adverse effects of low dissolved oxygen on fish life, the catch of fish per gill net set (Figure 9) was reduced at concentrations less than 3 mg/l.

In very eutrophic lakes, such as Klamath Lake, dissolved oxygen is often depleted in the deeper parts leaving much of the mass of water anaerobic for considerable periods of time. This was not the case in Klamath Lake. Although concentrations were slightly less near the bottom, there was only a small amount of stratification and then only during the warmer months. Unfortunately, no information on dissolved oxygen was obtained during time of ice cover.

Because the solubility of oxygen varies in respect to temperature and biological activity, dissolved oxygen observed at one time can be compared to that of another time best if the values are reported as percent saturation, assuming that influences other than temperature are similar. At Upper Klamath Lake an adjustment for an elevation of 4100 feet must be made. In Figures 10 and 11 surface and bottom observations in percent saturation at Hanks Marsh and Housepit Beach were plotted against temperature. In this illustration, temperature is also used as an index to season. At cooler temperatures that prevail from November through March, observed percent saturations were grouped around 75 percent, and there was little difference from one place in the lake

Table IV. Observed concentrations of dissolved oxygen considered to be detrimental to fish and wildlife during 1965 and 1966.

Date	Surface	Bottom	Zone
7-01-65	6.70	2.60	II
7-20-65	0.07	0.00	II
7-21-65	0.00	0.00	II
7-29-65	3.30	1.00	II
8-04-65	2.40	4.60	I
9-29-65	3.20	2.70	II
9-30-65	0.07	0.07	III
10-05-65	0.11	0.08	III
7-21-66	7.00	0.20	III

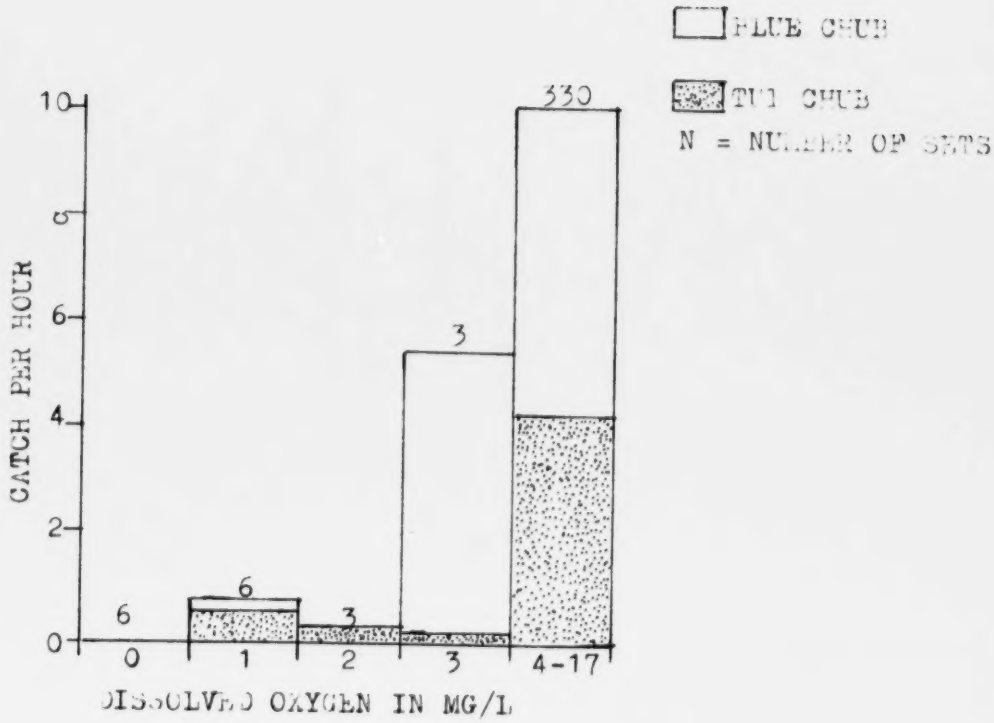

Figure 9. The relationship between the catch of chubs per hour in gill nets and the concentration of dissolved oxygen.

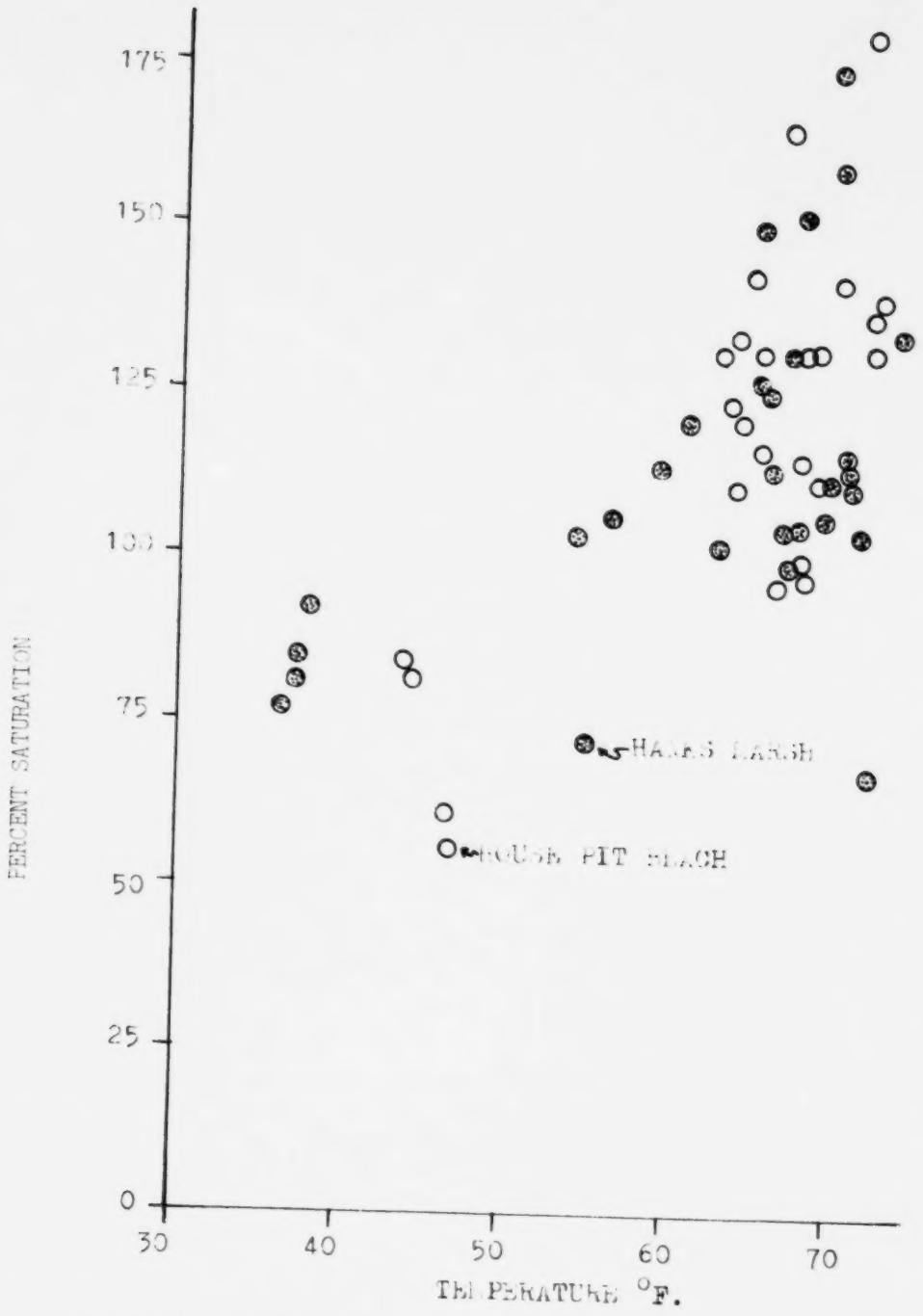

Figure 10. Per cent saturation of dissolved oxygen at a depth of one foot at two stations in Zone I during 1965-66.

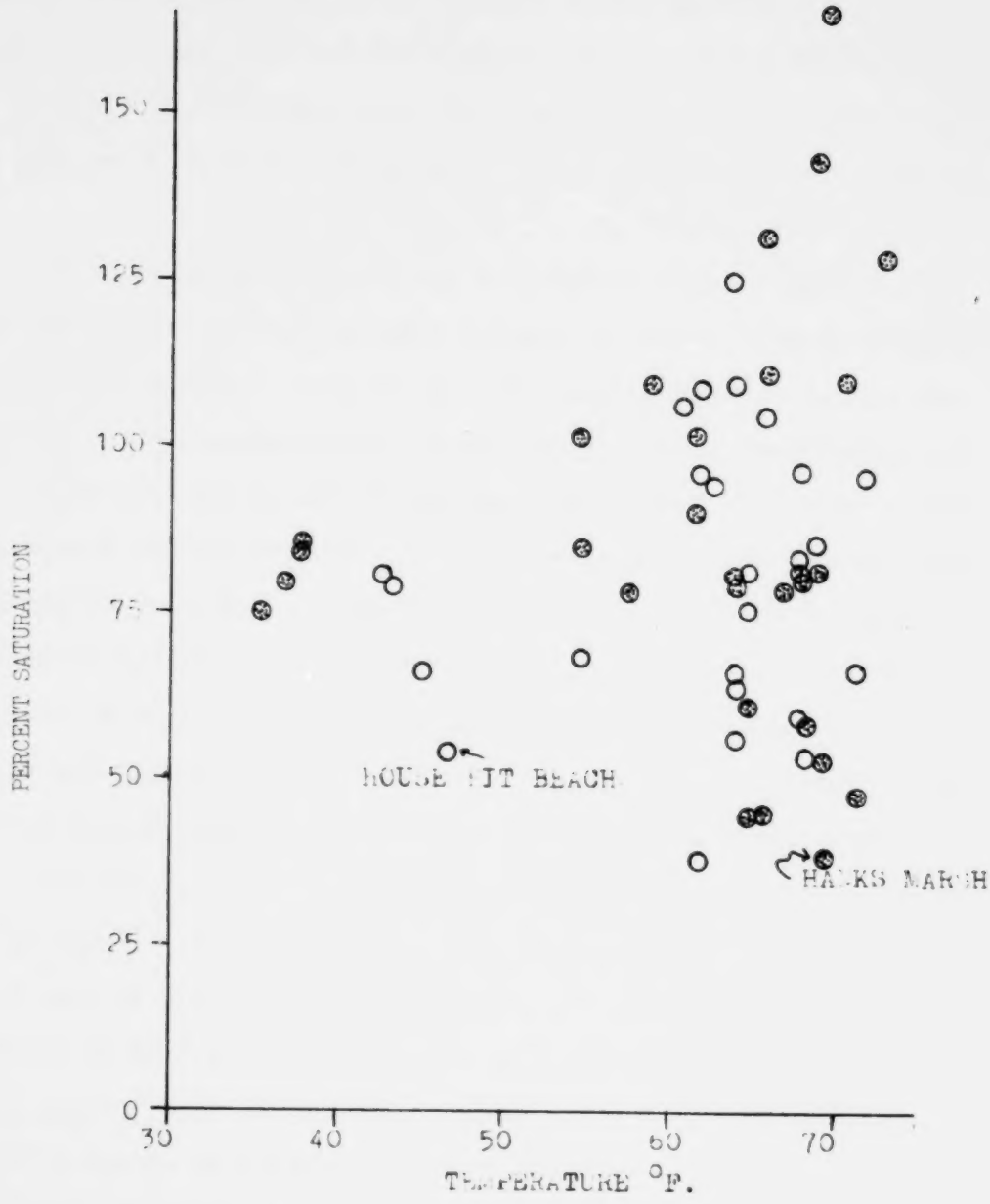

Figure 11. Per cent saturation of dissolved oxygen near the bottom at two stations in Zone I during 1965-66.

to another, or from surface to bottom. During this time of year, Aphanizomenon was not a dominant algal form. Melosira was dominant, and the lake was often very turbid due to the resuspension of bottom sediments. The range of observed percent saturation values at temperatures above 60° F was much greater than at colder temperatures.

In order to learn something of possible differences in levels of dissolved oxygen between the Standard Sampling Stations, percent saturations were plotted on normal probability paper as shown in Figures 12 through 16. The approximately linear distribution of points indicates (Li, 1960) that within the 60-70°F temperature range the observed percent saturations were made randomly distributed at each station. With all observations grouped, the mean for the bottom was at 80 percent and the surface at 120 percent saturation. Near the bottom, percent saturation was less than 50 percent about 10 percent of the time, and near the surface less than 50 percent about 1 percent of the time. We may infer from this analysis that during the warmer part of the season which lasts about 150 days, dissolved oxygen at saturations less than 50 percent may occur at midday on 2-5 days. In mg/l this means dissolved oxygen values less than 5.0 at 60°F and 4.5 mg/l at 70°F on 2-5 days. Actually, dissolved oxygen was found at some locations to be less than 5 mg/l on 16 of 57 days in 1965 and on 17 of 33 days in 1966.

The largest variation in oxygen concentrations were observed in Zone III. These variations were both between surface and bottom and between stations. The greatest differences occurred at the North Shore station. Near the bottom at North Shore percent saturations were below 50 percent about 35 percent of the time; conversely, surface readings remained near 100 percent saturation.

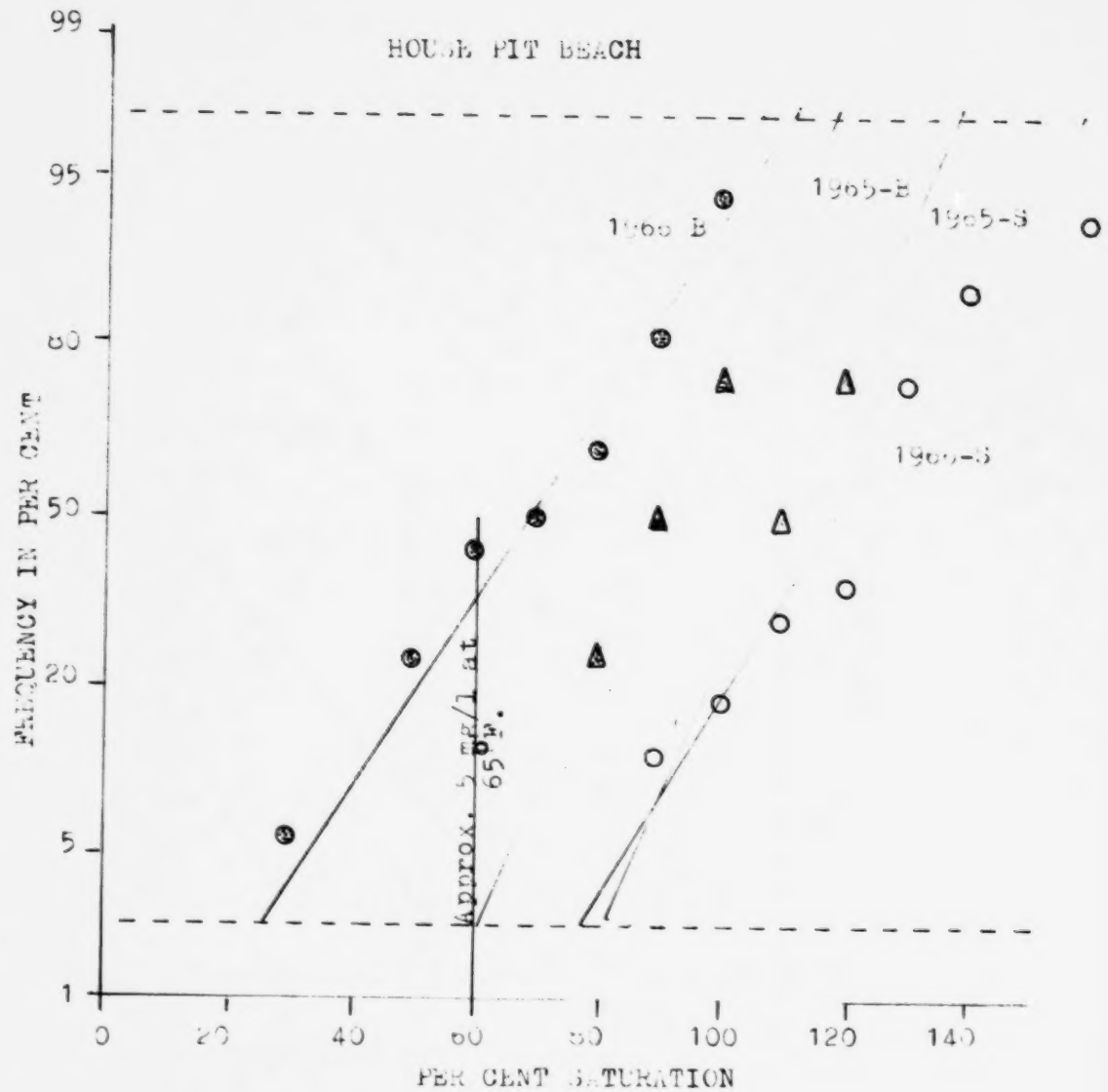

Figure 12. Grouped per cent saturations at surface and bottom at House Pit Beach for years 1965 and 1966, plotted on normal probability paper. Only those samples collected between 1000 and 1400 and 60 to 70°F. were used.

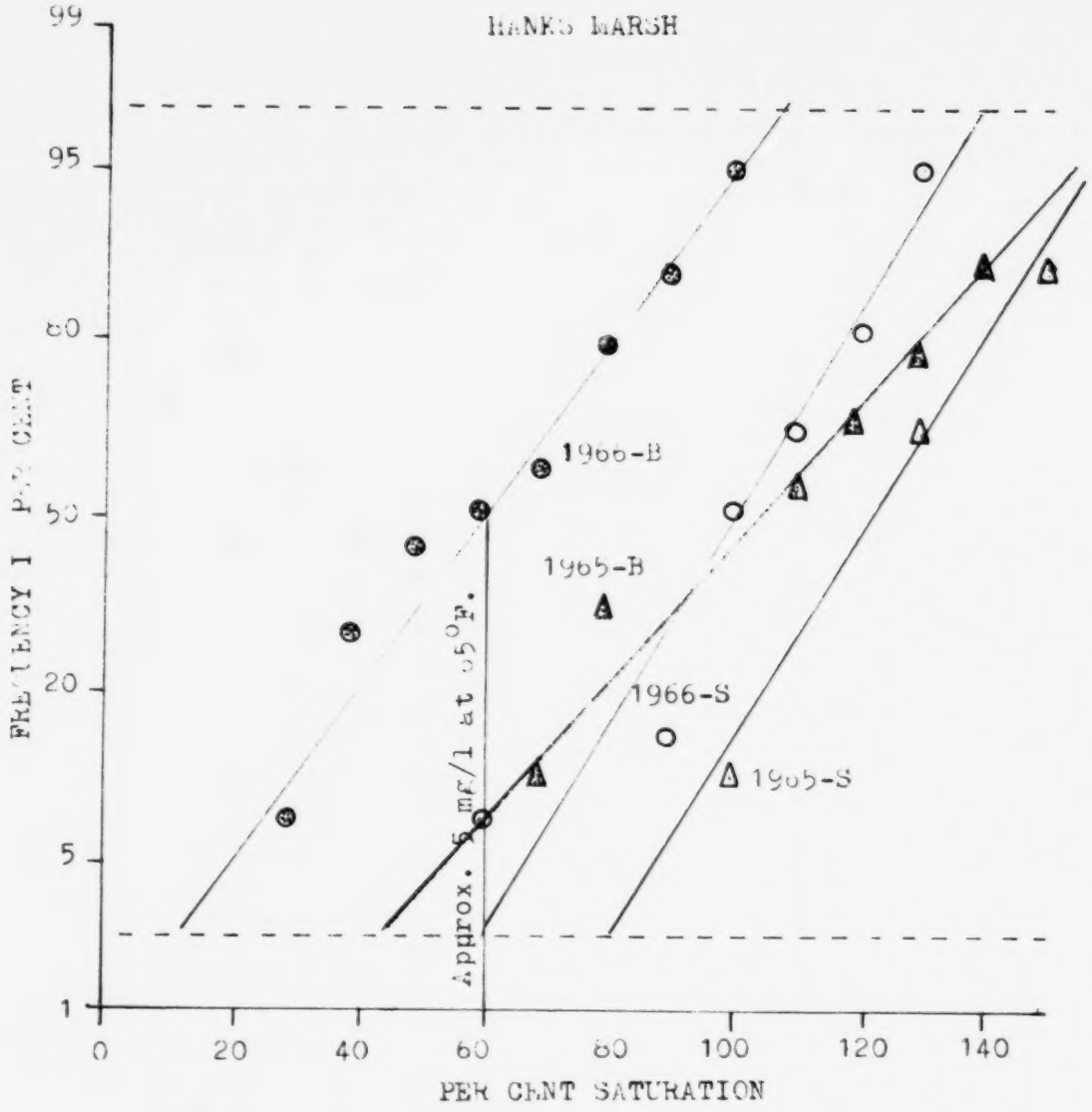

Figure 13. Grouped per cent saturations at surface and bottom at Hanks Marsh for years 1965 and 1966, plotted on normal probability paper. Only those samples collected between 1000 and 1400 hours and 60 to 70°F. were used.

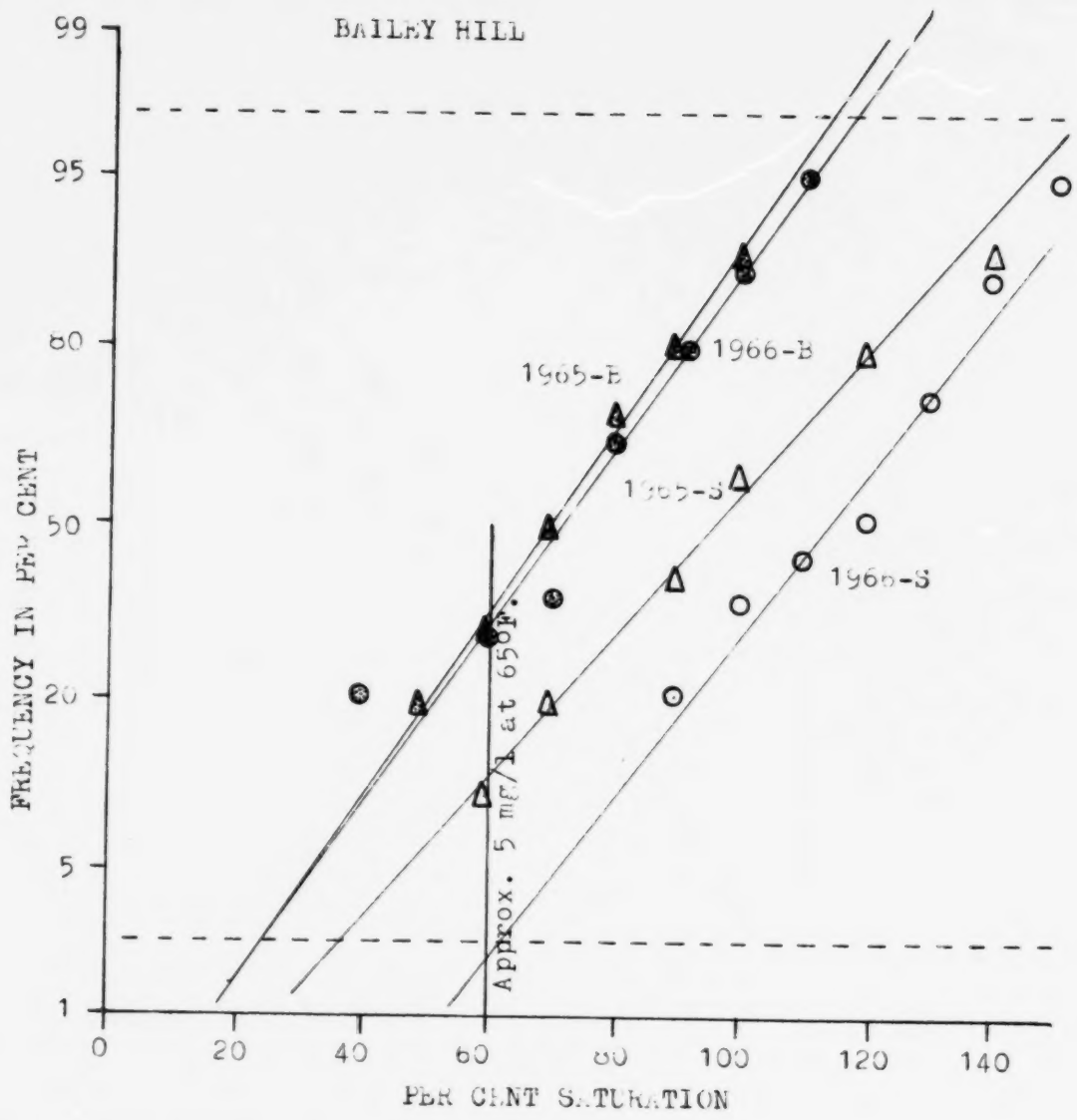

Figure 14. Grouped per cent saturations at surface and bottom at Bailey Hill for years 1965 and 1966, plotted on normal probability paper. Only those samples collected between 1000 and 1400 hours and 60 to 70°F. were used.

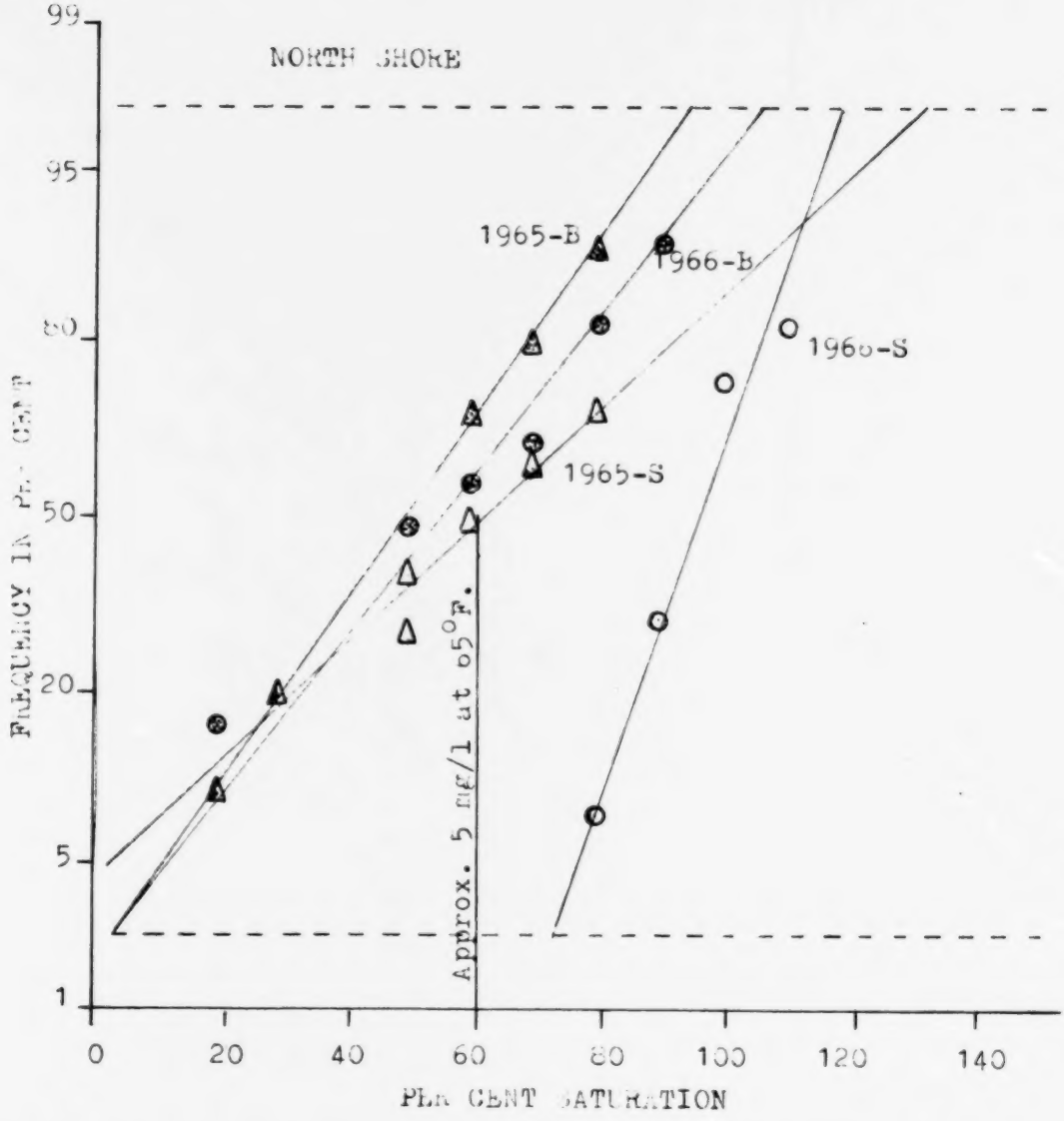

Figure 15. Grouped per cent saturations at surface and bottom at North Shore for years 1965 and 1966, plotted on normal probability paper. Only those samples collected between 1000 and 1400 hours and 60 to 70°F. were used.

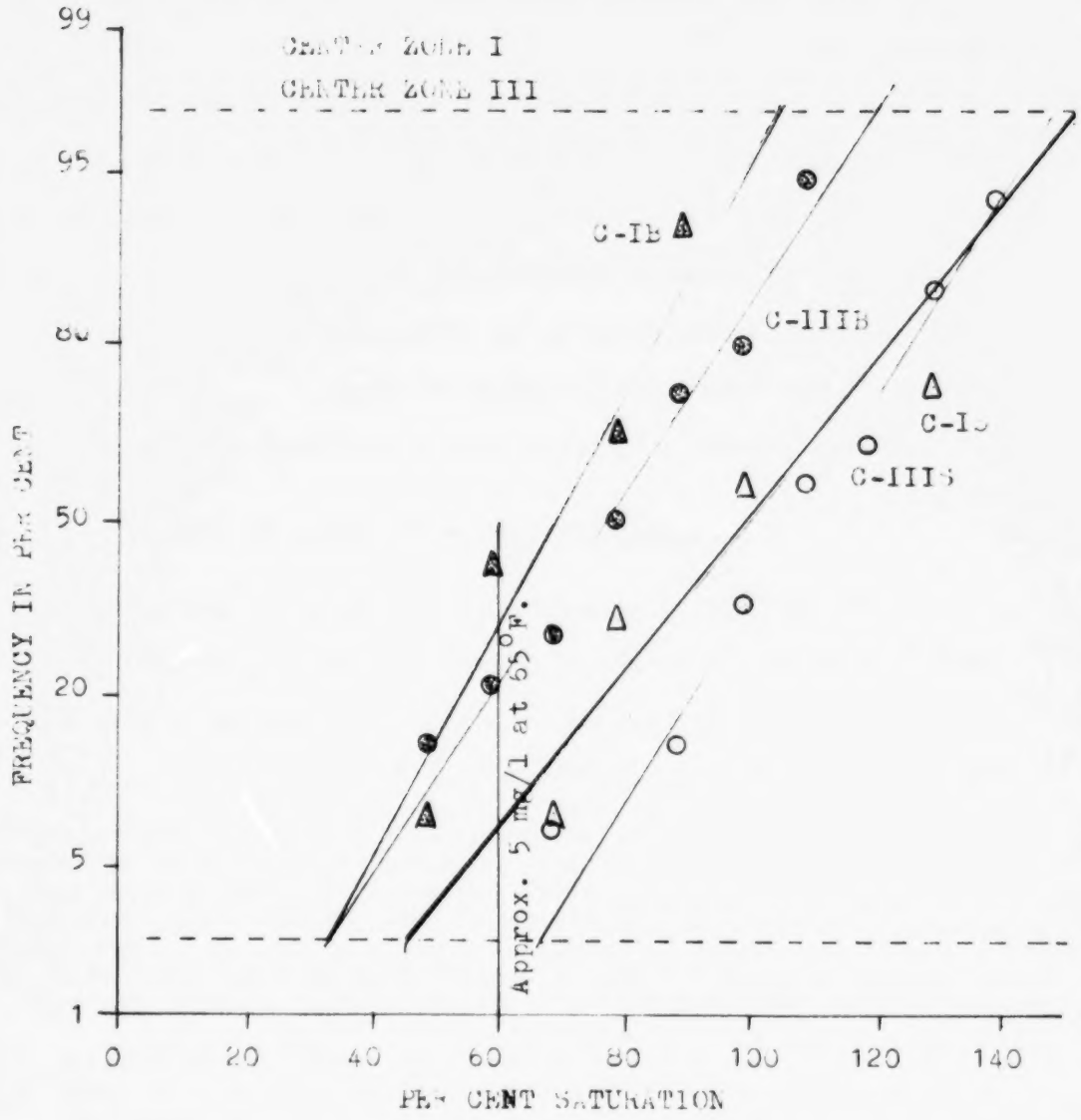

Figure 16. Grouped per cent saturations at surface and bottom at center of lake in Zones I and III for 1966, plotted on normal probability paper. Only those samples collected between 1000 and 1400 hours and 60 to 70°F. were used.

The center station in Zone III shows little difference between surface and bottom and also remains near 100 percent saturation. Observations at the center of the lake in Zones I and III were very similar to each other as shown in Figure 16.

Low concentrations of dissolved oxygen were observed to be a problem to fish only in Howard and Shoalwater Bays. During times when there was little wind, dissolved oxygen near the bottom lowered to less than 3 mg/l on many days but remained above 1 mg/l. Turbulence caused by the prevailing winds seems to be essential to the maintenance of dissolved oxygen levels near saturation throughout the column of water.

Diel variation in dissolved oxygen is usually about 4 mg/l (Figure 17).

Dissolved Oxygen at Mud Water Interface

Since sampling for dissolved oxygen with a Kemmerer bottle does not give information on concentration at the mud-water interface, a method described by Fremling and Evans (1963) that is reported to give this information was used. The method as described is as follows:

> "A 4 x 9-in. (ca. 10.1 x 22.9 cm) polyethylene bag (0.002 in., ca. 0.05 mm thick) is filled with 1 liter of tap water. Glass marbles are added for ballast and the bag is pulled downward into a container of water until the air in the bag is completely displaced. The neck of the bag is then tied, and several of the marbles are fastened with rubber bands inside three corners of the bag. Thus, weighted, the bag will conform to the lake bottom.
>
> Polyethylene is permeable to oxygen, and as soon as the bag enters the water, oxygen begins to diffuse from the regions of higher to regions of lower concentration. Diffusion will continue until the partial pressure of dissolved oxygen is the same within the bag and in the ambient water. In fresh water, the concentrations of dissolved oxygen in the bag and in the ambient water will be equal when the partial pressures are equal. This is not true in saline waters, however, and an appropriate correction would be necessary in the latter case.
>
> In deep water, the bag on the bottom is connected by a short line to an anchor marked by a buoy. In shallow

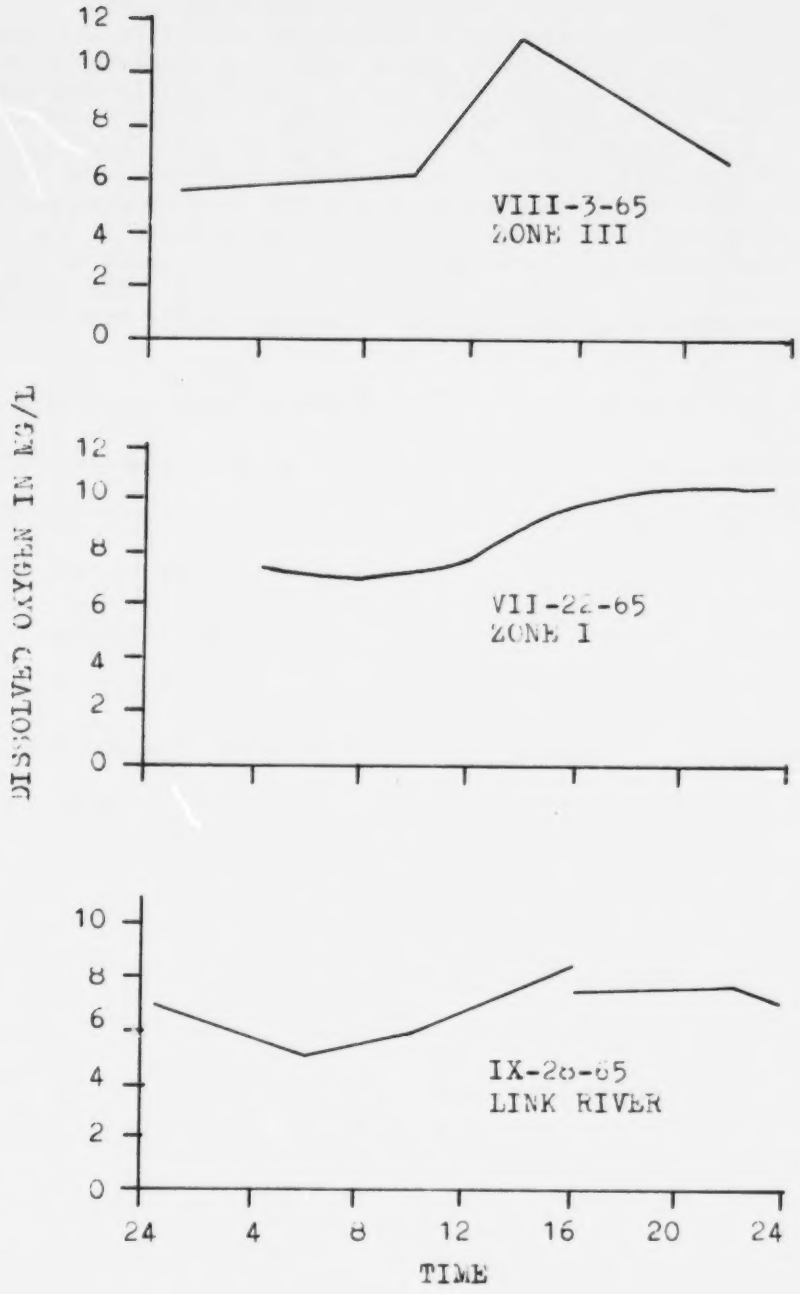

Figure 17. Examples of diel fluctuations in dissolved oxygen in Upper Klamath Lake, 1965.

> waters, the bag can be positioned by wading. The flexibility of the bag allows it to be placed in almost any niche.
>
> After the prescribed time, the bag is raised and immediately held over a large funnel which rests in a standard 300-ml dissolved oxygen sample bottle. The stem of the funnel is extended to the bottom of the bottle by rubber tubing. The bag is held over the funnel, the extreme tip of one corner is cut off with scissors, and the bag is quickly lowered into the funnel. The weight of the water in the bag makes an airtight seal between the bag and the sides of the funnel. The first water to enter the bottle is undoubtedly oxygenated, but the liter of water in the bag is sufficient to flush the bottle adequately. The sample is then treated according to the Standard Winkler method (Winkler, 1888)."

Our original attempts at using this technique were as described above except lead weights were used instead of marbles and an azide modification of the Winkler Method was used rather than the standard Winkler Method. Two bags were attached to a weighted line at distances of 16, 32, 48, and 66 feet from shore at each standard station. These distances correspond to varying depths (to 9 feet) which can be determined from descriptions of standard sampling stations in the methods section (Figure 5). Plastic bags remained in the lake for a period of three days before retrieval. Results of the first two experiments using the methods described above are shown in Table V.

During these tests dissolved oxygen determinations for the lake water and those observed for water in the bags were associated, but they did not directly correspond (Figure 18). Because in most cases the observed dissolved oxygen near the bottom was higher than that in the bags, it was assumed that dissolved oxygen in a thin layer over the bottom was significantly lower than in the remainder of the column of water. The weighted bags in the previous experiment did not always lie flat on the bottom. Wind-generated water currents were strong enough to move them. This was thought to have influenced the results. In order to secure the position of the bag on the bottom, a different type of anchoring system was devised.

Table V. Means of two determinations of dissolved oxygen content of water left in plastic bags on the bottom of Upper Klamath Lake, and observed dissolved oxygen at the bottom at the time bags were placed in and taken out of the lake. Duplicate bags were used at each location and time.

	Distance from shore in feet (approximate depth).					
	16(2)	32(5)	48(6)	66(7)	Bottom "in"	Bottom "out"
HOUSEPIT BEACH						
6/13 - 6/16	6.2	6.2	6.6	5.95	7.2	4.6
6/20 - 6/23	8.0	7.6	7.3	7.9	7.8	9.0
HANK'S MARSH						
6/13 - 6/16	6.45	6.25	6.3	4.9	7.8	8.6
6/20 - 6/23	5.5	4.6	5.5	6.0	7.6	9.8
BAILEY HILL						
6/14 - 6/17	6.2	5.3	4.65	5.4	6.0	9.4
6/21 - 6/24	8.5	9.1	6.8	3.7	10.4	8.6
NORTH SHORE						
6/14 - 6/17	4.2	-	4.2	5.1	7.2	9.0
6/21 - 6/24	6.6	6.4	6.7	6.4	7.6	4.6

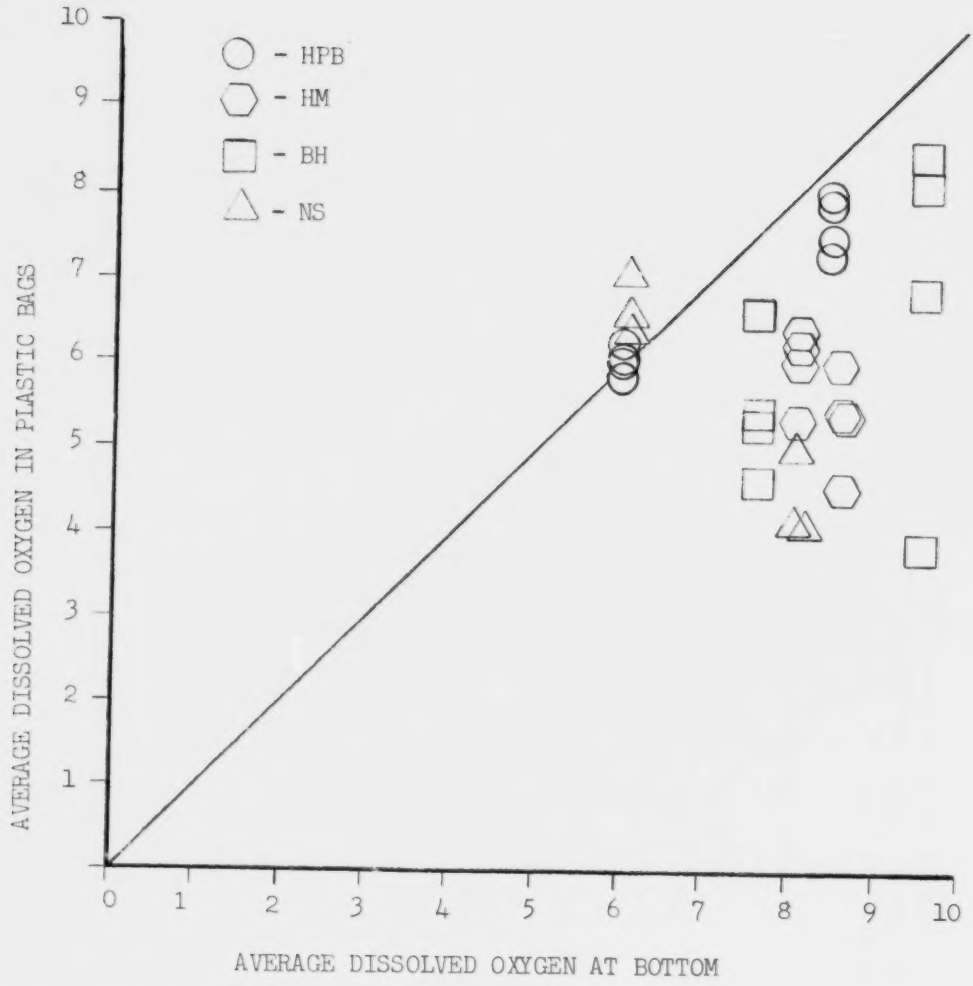

Figure 18. Relationship between the average dissolved oxygen at the bottom of the lake and in plastic bags on the bottom during June, 1966.

Garden hose was filled with lead shot and fastened together to form a hoop. Using nylon cord, bags were fastened inside the hoop in a manner so that they would lie flat on the substrate. The results of tests made after the modification are shown in Table VI. The dissolved oxygen at time of retrieval at surface and bottom was tabulated also.

The dissolved oxygen at the bottom appears to be lower in respect to distance from shore or increased depth. The fact that dissolved oxygen in the bag is closely associated with the concentrations in the lake can be ascertained by comparing test dissolved oxygen with that observed in situ.

Bags at the 16 foot locations were at a depth of about two feet and showed dissolved oxygen near that of surface water while the 48 foot locations, depths over 5 feet, correspond to dissolved oxygen in samples obtained from near the bottom with a Kemmerer sampler.

Dissolved oxygen in the bag was observed to be somewhat lower than in the surrounding water. Lowering of dissolved oxygen in the bag may occur because of the oxygen demand of the bottom sediments on which they rest. With the bag firmly positioned on the sediment, that part of the bag on the bottom would be subject to a constant withdrawal of oxygen whereas parts in contact with water may either gain or lose oxygen. In respect to equilibrium between the contents of the bag and the layer of water at the mud-water interface, this oxygen demand of the bottom sediments may tend to lower dissolved oxygen in the bag below what is actually the average in the surrounding water.

In order to obtain some idea of the oxygen demand of the bottom, duplicate bags were placed on the bottom in such a way that they were either shielded from the bottom or the overlaying column of water by a layer of 10 mil plastic. That is, oxygen transfer from the bag would be either between that contained

TABLE VI. THE AVERAGE DISSOLVED OXYGEN IN MG/L IN TWO PLASTIC BAGS AT LISTED LOCATIONS AND DATES. D.O. IN LAKE WAS TAKEN AT TIME OF RETRIEVAL AT SURFACE AND NEAR THE BOTTOM IN DEEPEST WATER AT STATION.

	Distances From Shore in Feet				
	16	32	48	Surface	Bottom
DATE					
HOUSEPIT BEACH					
7/15	6.8	6.4	7.0	9.0	3.2
7/21	3.9	7.2	2.4	13.4	4.1
8/12	8.4	9.0	7.8	10.2	6.5
8/20	8.1	5.6	5.8	10.2	7.2
8/31	4.9	4.6	3.1	10.6	6.2
Mean	6.42	6.56	5.22	10.68	5.44
HANKS MARSH					
7/15	4.0	5.3	3.0		
7/21		4.2	3.2	5.0	4.6
8/09	7.4	5.0	4.0	7.6	5.0
8/12	5.0	3.0	1.2	8.2	6.4
8/20	8.3	6.3	5.7	10.2	3.6
8/31	6.4	4.6	3.9	10.2	3.6
Mean	6.22	4.73	3.50	8.24	4.64
BAILEY HILL					
7/15	4.25	5.3	3.0	8.6	3.4
7/21	8.10	-	3.3	15.6	7.6
8/14	8.10	7.8	4.7	-	7.6
8/21	7.0	4.6	1.8	10.2	6.2
Mean	6.86	5.90	3.20	11.70	6.20
NORTH SHORE					
7/15	7.9	4.3	3.3	8.2	4.6
8/14	7.7	7.9	5.0	-	4.6
8/21	7.4	7.0	2.4	7.6	4.8
Mean	7.67	6.40	3.57	7.90	4.67

in the bag and either the sediments or the water column. Naturally the isolation of water and sediments could not be done with 100 percent efficiency, but it did give interesting results (Table VII).

After August 10 the concentration of dissolved oxygen in bags open to the water but shielded from sediments was much lower than had previously been observed in other similar tests and in non-shielded tests carried out at about the same time and place (See Hanks Marsh, Table VI). The hoop and shielding apparatus may have reduced water movement around the bags, thus reducing the inflow of higher oxygen concentrations from above. Also, organic debris may have collected on and around the bag.

Bags resting on the sediment and shielded from the water column showed consistency in the amount of oxygen lost per day over the incubation period. With all bags grouped the mean and standard deviation are 0.91 mg/l and 0.50 mg/l, respectively.

Water Mass Movement

A four-finned drogue was used to obtain an idea of the velocity of water mass movement at four standard sampling stations (H.P.B., H.M., B.H., and N.S.). The aluminum fins were 18" x 18" giving a total width of 36". The fins were supported on a brass chain from a polystyrene float that was weighted to a point where it barely floated, leaving only 1/8 to 1/4 inch above the surface. This technique lessened the direct effect of wind on drogue movement. The center of the fins was suspended at a depth of three feet. The drogue was used in water depths from six to nine feet.

To measure movement the drogue was released from a point marked by an anchored bouy to which it was attached by 25 feet of monofilament fishing line. The time required to extend this line, direction of travel, and an arbitrary estimate of wind velocity were recorded.

TABLE VII. THE CONCENTRATION IN MG/L OF DISSOLVED OXYGEN AT RETRIEVAL AFTER 7 DAYS INCUBATION IN BAGS EITHER SHIELDED FROM WATER OR SEDIMENT AND IN BAGS* AT START OF TEST.

Depth in Feet.	2			4			6			
POSITION	In Water	On Sed.	Sed. Demand	In Water	On Sed.	Sed. Demand	In Water	On Sed.	Sed. Demand	In bags at start
8/05/66	4.6	0.5	5.7	4.7	0.4	5.8	4.4	0.1	6.1	6.2
8/10/66	5.3	1.5	6.5	5.1	0.6	7.4	4.4	0.0	8.0	8.0
8/17/66	1.4	1.1	5.1	1.6	1.2	5.0	1.7	0.5	5.7	6.2
9/10/66 (10 days)	1.5	0.0	8.0	0.9	0.0	8.0	1.1	0.2	7.8	8.0
Mean demand per day in Mg/L.			0.87			0.90			0.93	

*Bag resting on bottom covered approximately 0.28 sq. ft. and contained approximately 1.25 liters of tap water.

The results of these tests are in Table VIII. Drift rates were from zero to 0.208 feet per second(749 feet per hour). Velocities were comparable in mean and range between B.H., H.P.B., and H.M., but were noticeably less at N.S. During periods of north wind, N.S. is protected by a lee shore which may account for the difference.

Generally, velocity of movement was to some extent proportional to estimated wind velocities except at H.P.B. There appeared to be an eddy at this station during periods of strong wind (Figure 19). Because wind velocities were broadly estimated the values represent wind speed in a relative manner from none to very strong. Estimated velocities correspond generally with data recorded at the southern end of the lake by instruments of the Pacific Power and Light Company. At winds estimated to be 10 to 15 mph waves were about 6 inches high and were 18 inches high at 25 mph.

Resuspension of Bottom Sediments

Sediments over most of the bottom of Klamath Lake seem to be resuspended, almost daily, by wind-induced currents during most of the year. These periodic additions to the water mass of particulate matter from the bottom are not completely accounted for in measurements of seston especially if we assume that these resuspended particles settle out faster than other components. This assumption seems reasonable since the larger fractions of the seston during summer are Aphanizomenon and zooplankton which usually do not settle while alive.

To obtain some idea of the flux of particulate matter between the bottom and the overlying water, the sampling gear illustrated in Figure 20 was constructed and placed in the lake at four locations for 24 hours on eight days between July 5 and August 24, 1966. Samplers were placed in six to

TABLE VIII. VELOCITY OF WATER MASS MOVEMENT AT FOUR STANDARD STATIONS.

Date 1966	Depth Feet	Estimated Wind Vel. (mph) -Dir.	Drogue Vel. (fps) -Dir.
		HOUSE PIT BEACH	
7/ 5	9	0	0.034-S
7/ 6	9	12-S	0.083-N
7/12	6	0	0.018-N
7/13	6	3-N	0.104-S
7/20	10	7-N	0.104-SSW
7/21	10	10-N	0.092-SSW
7/27	12	5-N	0.060-SSE
7/28	12	0	0.000
8/ 4	9	5-N	0.060-S
8/ 5	9	25-N	0.104-S
8/ 9	8	20-N	0.104-SSW
8/10	8	15-N	0.092-SSE
8/17	8	5-N	0.076-SSW
8/18	8	5-N	0.006-SSE
8/24	9	25-S	--
8/25	9	7-S	0.060-NE
	Mean	9	0.066
	Range	0-25	0- 0.104
		HANKS MARSH	
7/ 5	8	15-S	0.007-N
7/ 6	8	5-N	0.205-S
7/12	8	0	0.006-S
7/13	8	5-N	0.028-SSE
7/20	7	5-N	0.042-S
7/21	7	10-N	0.042-S
7/27	8	5-N	0.028-S
7/28	8	0	0
8/ 4	8	5-N	0.060-SE
8/ 5	8	25-N	0.125-S
8/ 9	7	5-N	0.060-S
8/10	7	15-N	0.069-SSE
8/17	7	5-N	0.060-SSE
8/18	7	5-N	0.040-SSE
8/24	8	25-S	0.208-NW
8/25	8	7-S	0.038-NW
	Mean	9	0.064
	Range	0-25	0- 0.208

TABLE VIII. Continued.

BAILEY HILL

Date 1966	Depth Feet		Estimated Wind Vel-Dir.	Drogue Vel.-Dir.
7/ 6	6		7-N	0.083-E
7/ 7	6		20-E	0.208-NW
7/12	8		10-N	0.104-N
7/13	8		10-N	0.083-N
7/20	7		5-N	0.038-SSE
7/21	7		5-N	0.035-SSE
7/28	5.5		0	0.000
7/29	5.5		0	0.000
8/11	8		5-NW	0.035-SSE
8/12	8		5-N	0.035-S
8/23	7		0	0.000
8/24	7		15-S	0.042-SE
		Mean	7	0.055-
		Range	0-20	0- 0.208

NORTH SHORE

7/ 6	6		5-NW	0.083-E
7/ 7	6		1-SE	0.104-W
7/12	7		5-N	0.035-E
7/13	7		10-NE	0.060-E
7/20	7		0	0.000
7/21	7		0	0.000
7/28	6		0	0.000
7/29	6		0	0.000
8/11	9		5-NW	0.006-SE
8/12	9		5-N	0.056-E
8/18	7		15-N	0.055-E
8/19	7		5-N	0.044-E
8/23	8		0	0.000
8/24	8		15-S	0.059-E
		Mean	5	0.036
		Range	0-15	0- 0.104

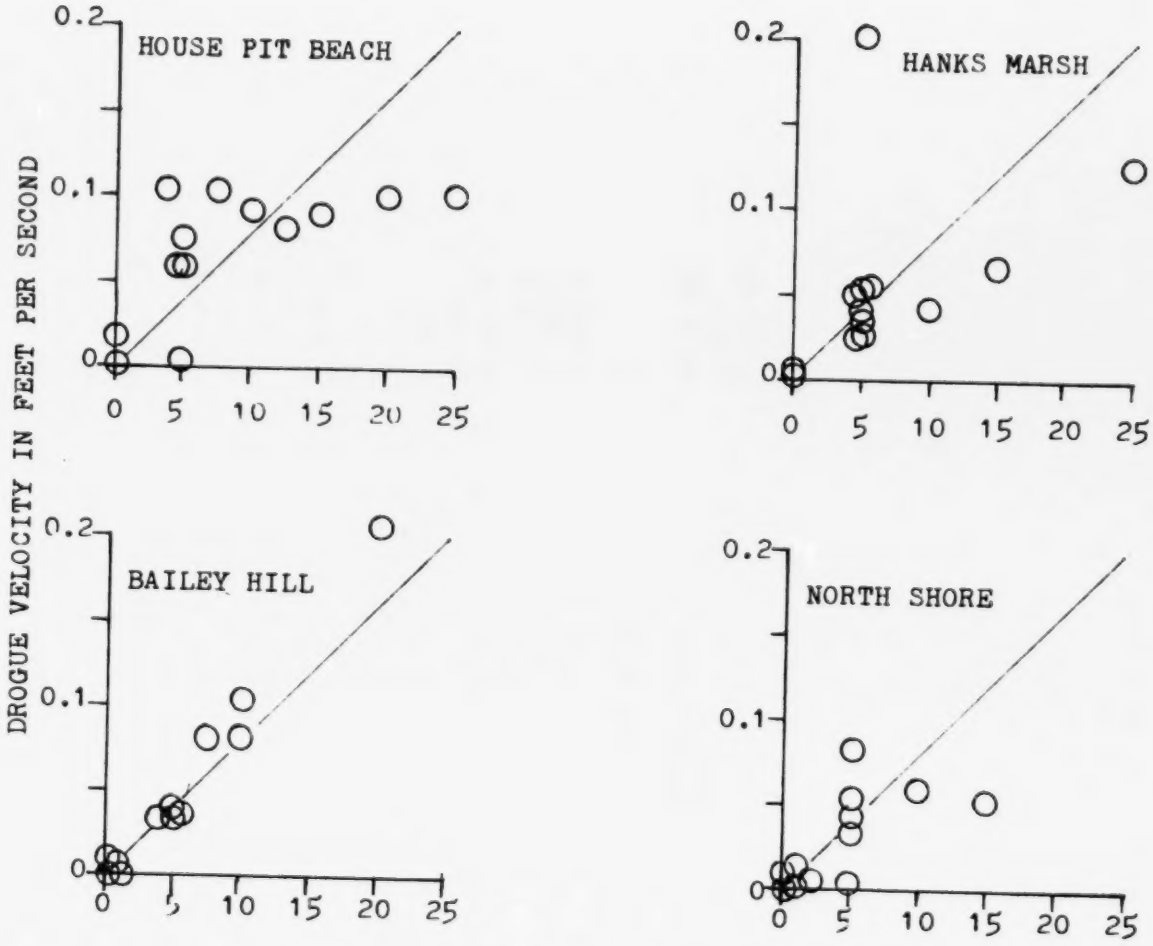

Figure 19. Relationship between estimated northerly wind velocities and drogue movement.

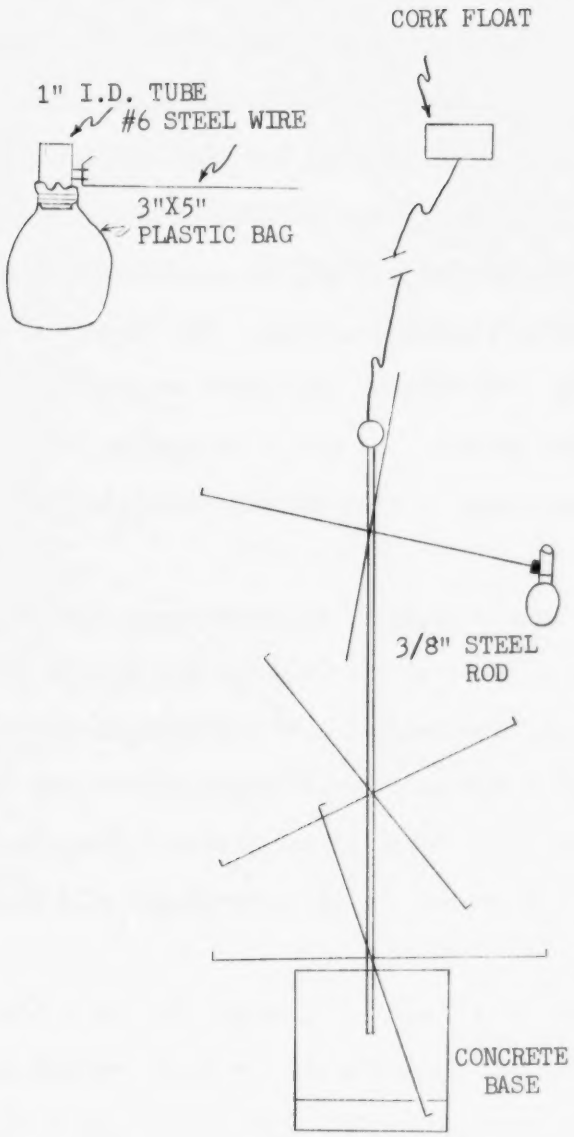

Figure 20. "Christmas-tree" sampling device used to estimate flux of resuspended sediments.

eight feet of water on a level bottom 25 to 50 yards from shore.

The residue collected in 3 x 5 inch plastic containers was rinsed into 32 oz. jars, returned to the laboratory, centrifuged, decanted and then rinsed from the centrifuge tubes with distilled water into tared pans. These pans were dried at 55°F overnight and then weighed. The dry residue was oxidized with 30 percent hydrogen peroxide, added at about 15 ml per two grams of dry residue, and the resulting loss of weight was used as an estimate of organic content. The results of 31 such tests are given in Table IX. The mass of settleable material collected is expressed as $mg/cm^2/24$ hours at the specified depths. Mean organic matter in $mg/cm^2/24$ hours was computed from the individual samples at a particular depth.

Live organisms such as Daphnia, Aphanizomenon, and Chironomus were often trapped in the collectors. Zooplankters and benthos large enough to be seen by the unaided eye were removed from centrifuged samples before drying. The average number of different kinds of organisms removed from the collecting tubes are given in Table X. With the exception of Oligochaeta and Tendipedidae, organisms caught in the sediment traps corresponded with those found in samples of zooplankton.

The accumulation of sediment was greater the nearer the sampler to the bottom (Figure 21); however, the organic fraction lessened slightly nearer the bottom. The stations adjacent to marshes (N.S. and H.M.) had higher organic content than those near rocky beaches (B.H. and H.P.B.).

An association was observed between the total sediment obtained and velocity of water mass movement as determined with the drogue (Figure 22).

TABLE IX. THE DRY WEIGHT OF SESTON IN MILLIGRAMS PER SQUARE CENTIMETER COLLECTED IN 24 HOURS AT DISTANCES OF 6, 18, and 36 INCHES FROM THE BOTTOM.

Date-1966	7/5	7/12	7/20	7/27	8/4	8/9	8/17	8/24	Total Seston Mean	Organic Seston Mean	%Organic Seston
HOUSE PIT BEACH											
36"	48	35	344	140	312	241	155	57	166	23	14.0
18"	141	3178	1030	594	1378	456	1170	721	1084	114	10.5
6"	1957	4902	2012	3555	2582	479	3390	2814	2712	275	10.1
HANKS MARSH											
36"	--	177	146	563	731	628	719	232	456	81	17.7
18"	--	306	648	2044	1256	1636	2077	820	1255	235	18.7
6"	--	1969	1008	3335	2736	1345	4459	2899	2536	427	16.8
Date-1966	7/6	7/12	7/20	7/28	8/5	8/11	8/18	8/23			
BAILEY HILL											
36"	160	17	104	808	29	114	150	569	244	35	14.3
18"	754	524	277	1134	801	880	1166	563	762	169	22.2
6"	2130	562	2728	3875	3403	1286	3296	2822	2537	389	15.3
NORTH SHORE											
36"	22	88	82	16	49	408	251	113	129	31	24.2
18"	45	132	742	61	558	472	217	658	360	87	24.0
6"	1578	4437	2193	1194	2067	1553	3156	3555	2467	528	21.4

TABLE X. AVERAGE NUMBER OF ORGANISMS REMOVED FROM COLLECTION TUBES POSITIONED 6, 18, and 36 INCHES FROM THE BOTTOM.

	TENDIP-EDIDAE	CLAD-OCERA	COPE-PODA	AMPHI-PODA	ISO-PODA	OSTRA-CODA	EPHEMER-OPTERA	OLIGO-CHAETA
HOUSE PIT BEACH (N=8)								
36"	2.38	12.85	0.43	0	0.43	0.71	0	0.28
18"	1.37	7.71	1.57	0	0	1.00	0.14	0.14
6"	1.65	8.00	0.14	0	0	0.43	0	0.14
HANKS MARSH (N=7)								
36"	1.57	14.86	0.71	0	0	1.71	0	0.14
18"	1.57	15.14	0.29	0.14	0	1.71	0	0.14
6"	1.00	19.43	0.29	0	0	1.86	0	0.14
BAILEY HILL (N=8)								
36"	0.71	10.43	0	0	0	0.29	0	0.14
18"	2.43	9.29	0	0	0.57	1.71	0	0
6"	6.43	15.00	0.57	0	0	6.71	0	0.29
NORTH SHORE (N=8)								
36"	1.00	7.28	0.86	0	0	1.71	0	0.43
18"	1.14	15.00	0.14	0	0	2.14	0	0.29
6"	0.14	12.85	0.43	0	0	3.00	0	0.14

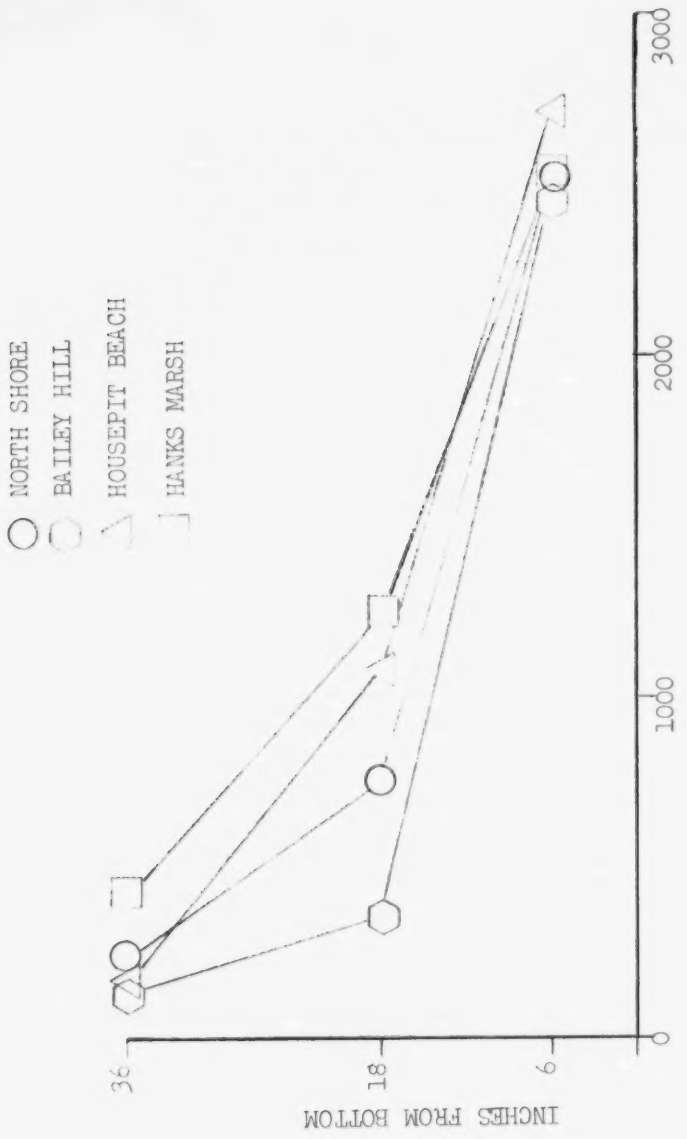

Figure 21. The average dry weight of settleable solids collected at three depths at four standard stations.

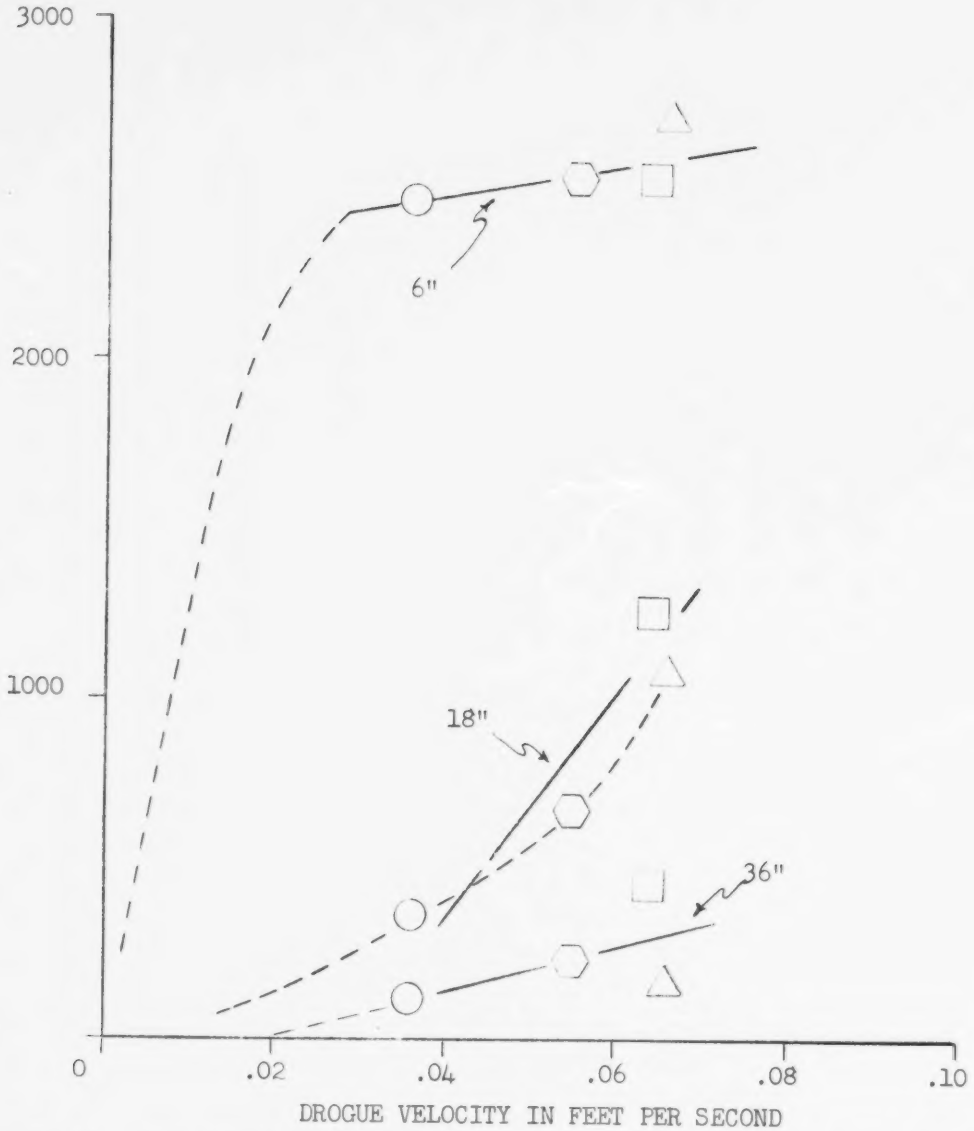

Figure 22. The relationship between mean settleable solids collected at three depths and the velocity of water mass movement.

With increases in drogue velocity there were increases in the amount of sediment captured. Theoretical lines of sedimentation per day at different water mass velocities are also shown as dotted lines. This association was most evident at the 18 inch location but only slightly noticeable at 36 inches. The samplers 6 inches from the bottom probably filled during the early part of a 24 hour period and then failed to function in a manner comparable to samplers located at the other two depths.

From a cursory analysis of the data bottom sediments appear to be re-suspended when water mass movement has a velocity greater than about 0.02 feet per second or when wind velocities are two to five miles per hour. The average wind velocity recorded at the weather station at Klamath Falls is 6.1 miles per hour and monthly means range from 4.7 to 7.7 during the ice-free months. Thus, during ice-free months bottom sediments are probably in daily flux with the overlying water mass. A preponderance of this flow of particulate matter occurs in the lower three feet of the water column.

Sediments

Two samples of sediments were taken at each location with an Ekman Dredge and placed in plastic bags, labeled, and returned to the laboratory for mechanical analysis. Samples were split into sizes convenient for analysis, and one aliquot was dried and weighed. Another sub-sample was washed through sieves with openings of 12.7, 2, 1, 0.5, 0.25, 0.125, and 0.088 mm. Sediments retained by these sieves were dried and weighed. The difference between the totals of these separate weights and the starting weight was taken to be the weight of the fines which passed through the 0.088 mm sieve.

Miller and Tash (1967) report that "The quantity of nitrogen and phosphorus in only the upper 1 inch of lake sediments is as great as that quantity which would flow into the lake during the next 60 years if the present rate of inflow continues". Their chemical analysis of bottom sediments is given in Table XI. Many other nutritive elements are also very abundant.

An estimate of the organic content of bottom sediments was made using two different methods. Aliquots of samples from the center of Zones I and III were ozidized with 30 percent hydrogen peroxide and in a Parr 1411 Colorimeter. For Zone I, hydrogen peroxide oxidation indicated an organic content of 69.5 mg/gr dry weight (N=10, standard error = 4.45). Colorimeter results were 197.5 mg/gr (N=2).

Organic content for Zone III by hydrogen peroxide was 69.7 mg/gr (N=10, Standard Error = 4.32), and by colorimetry it was 198.1 mg/gr (N=2). In respect to these two tests there appears to be little difference in the organic content of bottom sediments between Zones I and III. The size of particles in eighty to ninety percent of sediments in the open lake are less than one-tenth millimeter (Figure 23). Undisturbed sediments during the summer may be brown to black in color and appear to be flocculent. Under magnification these sediments look very similar to the fecal pellets of invertebrates. The residue left after oxidation with hydrogen peroxide is diatom frustules. The larger particles that show up during mechanical analysis are vascular plant fibers. A very large proportion of the bottom of the lake is covered with this type of sediment.

Different types of sediments are found near shore. These bottom types range from large boulders (Eagle Ridge), to small sand (mouth of Williamson River) and Peat (marshes). However, in almost all cases these near shore sediment types grade to fines in water 6 to 8 feet deep at 100 feet or so from shore.

Table XI. Bottom Sediment Analysis (Acid Soluble)[1]

Constituent	Micrograms/gram Dry Weight	Tons in Lake Area 1 Inch Deep
Aluminum	1,750	34,665
Barium	25	496
Beryllium	0.04	0.8
Boron	98	1,942
Cadmium	14	28
Calcium	3,900	77,271
Chromium	4	79
Cobalt	7	139
Copper	4	79
Iron	11,400	235,870
Lead	14	278
Manganese	183	3,626
Nickel	7	139
Ammonia Nitrogen as N	270	5,349
Nitrate Nitrogen as N	150	2,972
Organic Nitrogen as N	3,400	67,364
Total Phosphorus as P	1,600	31,701
Potassium	1,560	30,910
Silicon as Si	24,000	475,517
Silver	0.70	14
Sodium	780	15,453
Strontium	5	99
Sulfur as S	2,500	49,533
Vanadium	14	28
Zinc	14	28

[1] Miller, W. E. and J. C. Tash. 1967. Interim Report Upper Klamath Lake Studies, Oregon F.W.P.C.A. Publ. WP-20-8.

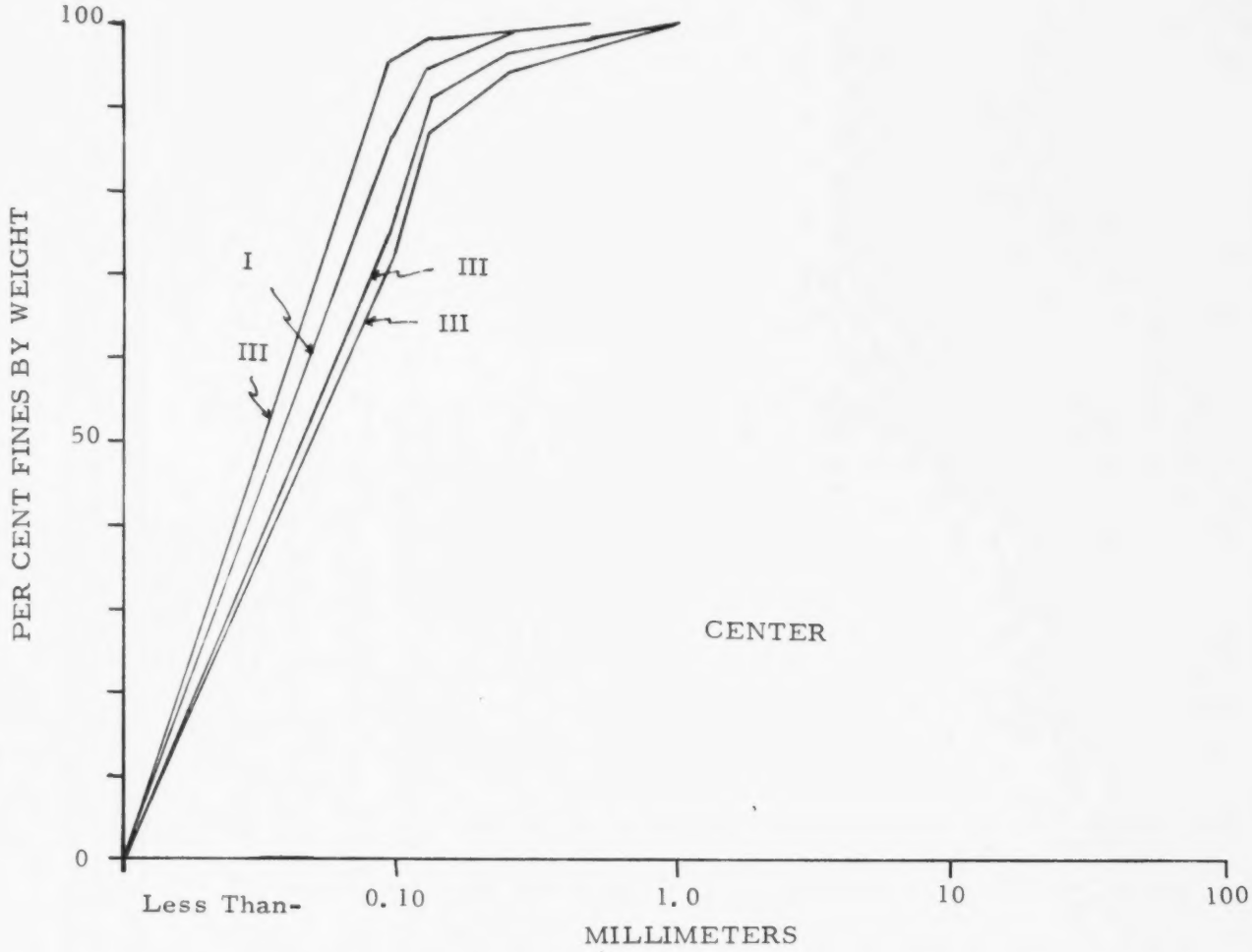

Figure 23. Results of mechanical analyses of sediments collected from center of Klamath Lake in Zones I and III.

In order to describe the substrates at four standard stations, sediment samples were collected at 10 foot intervals from the high water mark to a distance of 100 feet from shore. The results of these analyses are shown in Figures 24, 25, 26, and 27. At Hanks Marsh and North Shore the larger particles are root and leaf remains from marsh plants. The finer components are similar in composition to those farther out in the lake except they are more compact. The larger plant remains at distances of 80, 90, and 100 feet at Hanks Marsh are in deep water and mixed into the compact mud bottom.

The graded sand and gravel at Housepit Beach extend more than 100 feet off-shore to water depths of 10 to 15 feet. Southerly storms periodically scour this beach.

Sediments at Bailey Hill grade from gravel and granular near shore to fine sand at distances of 50 to 80 feet from shore. Much of the larger sized matter at 90 and 100 feet from shore was tree limbs, bark, and other plant materials.

Since much of the surface layer of the bottom is resuspended periodically, the fines that are on rocky beaches are very unstable. With an almost daily resuspension of bottom sediments rich in elemental and organic nutrients, there is no conceivable shortage of nutritive matter for most planktonic and benthic animals, but with a pH near 10 there may be a carbon shortage for algae.

Algae

Phinney and Peek (1960) report that at least 29 species of algae occur in Upper Klamath Lake. Four species of bluegreen and two diatoms are most abundant. From May to November 90 to 99 percent of the algal population

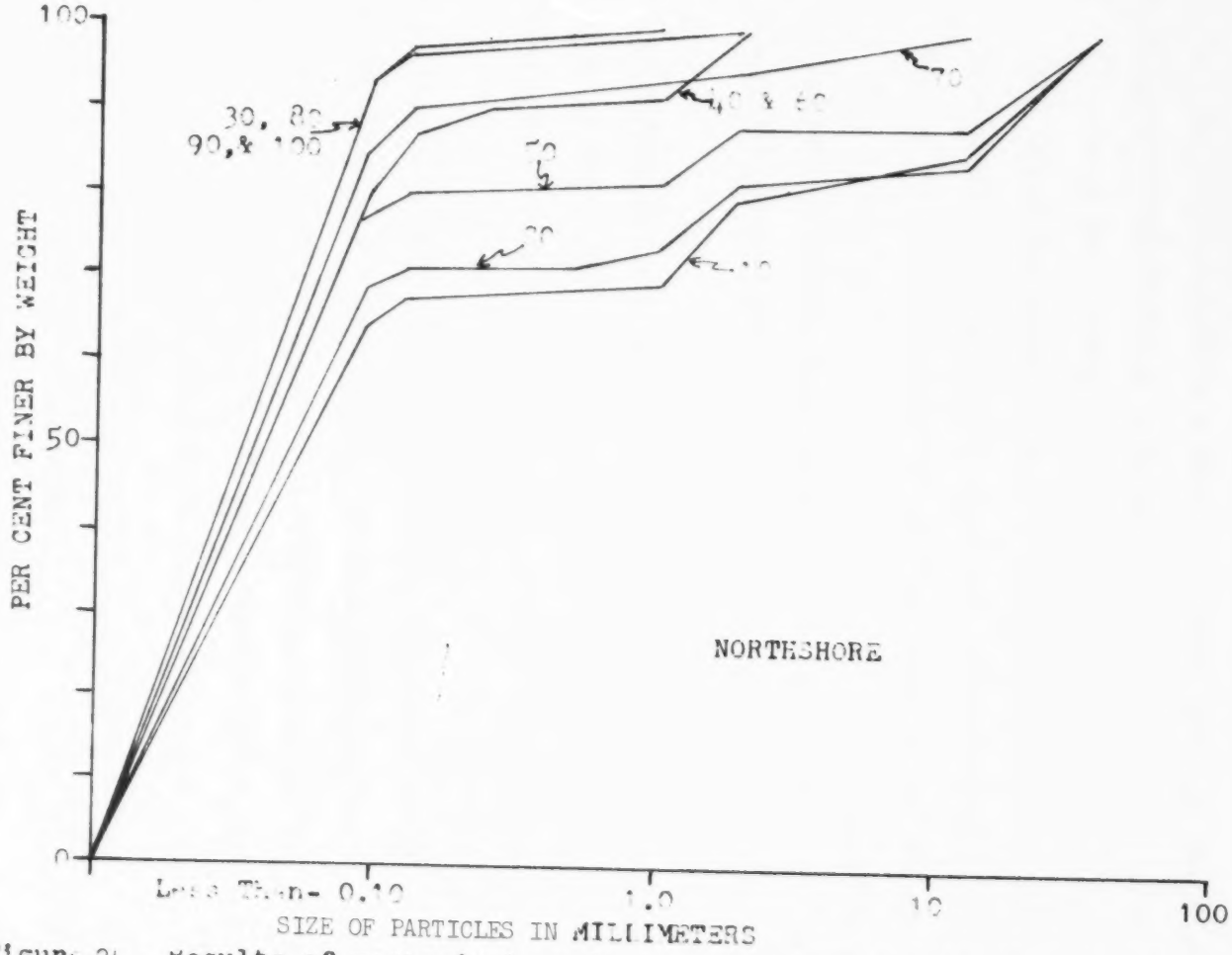

Figure 24. Results of mechanical analyses of sediments collected at 10 foot intervals from the highwater mark at North Shore station.

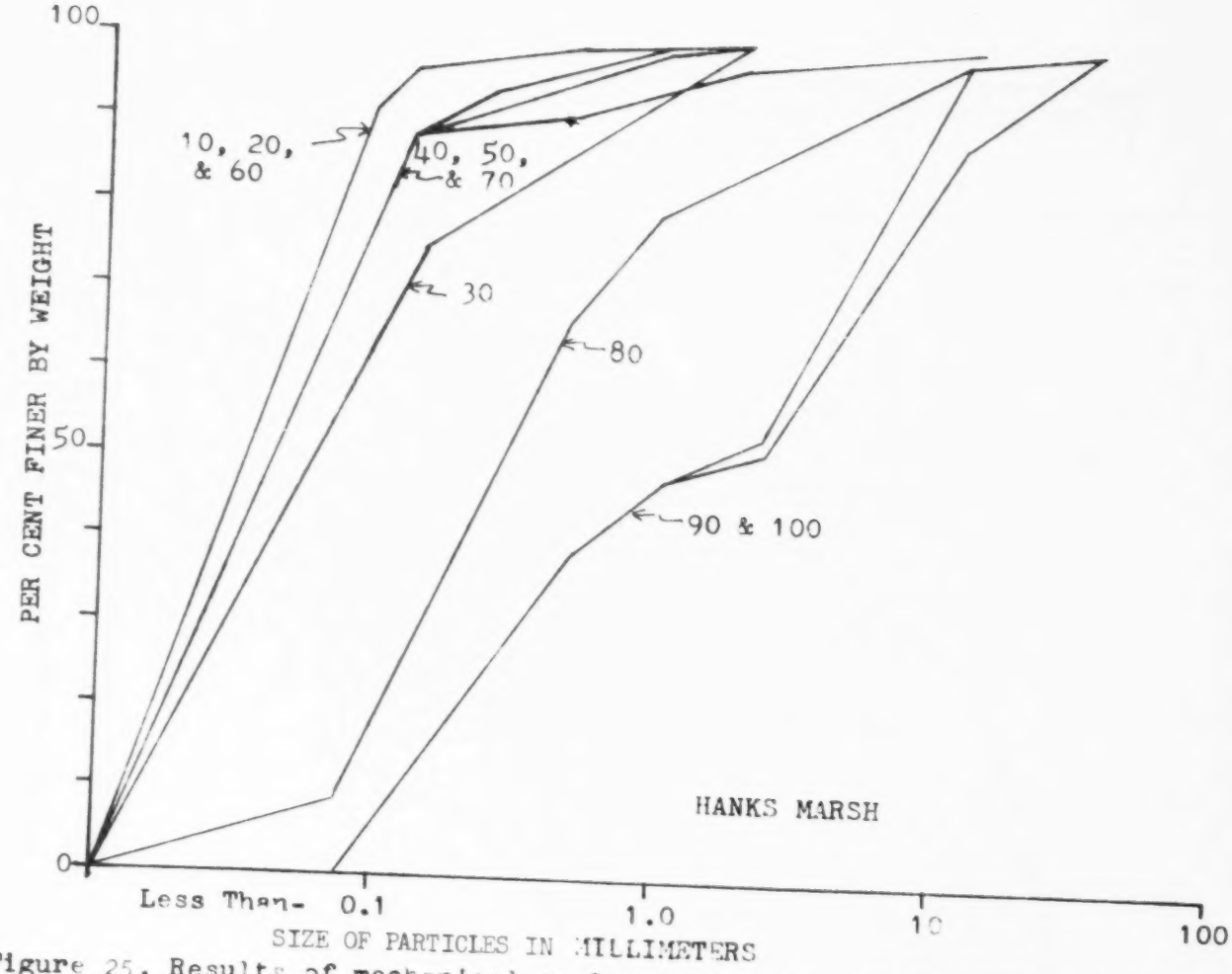

Figure 25. Results of mechanical analyses of sediments collected at 10 foot intervals from the highwater mark at Hanks Marsh station.

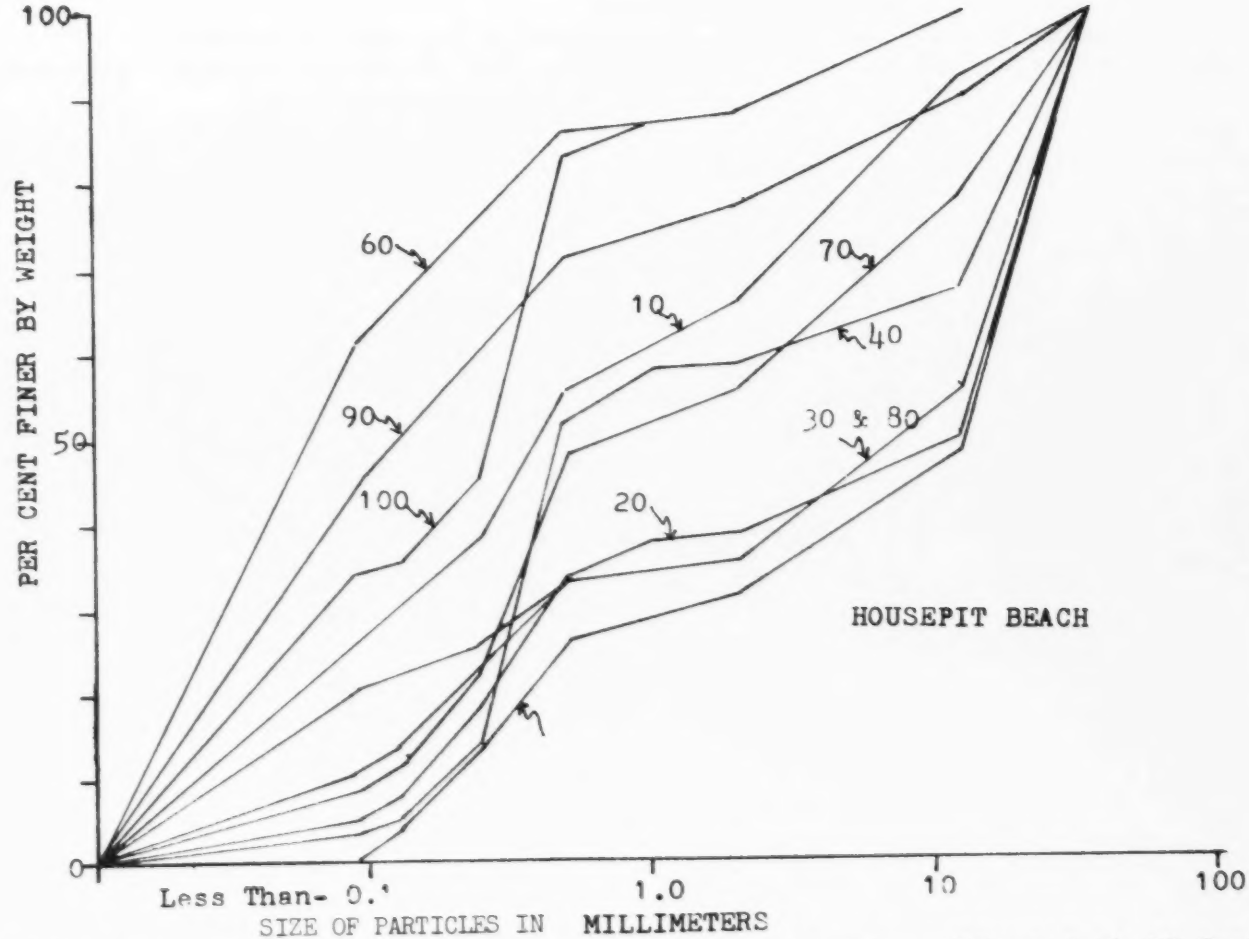

Figure 26. Results of mechanical analyses of sediments collected at 10 foot intervals from the highwater mark at Housepit Beach station.

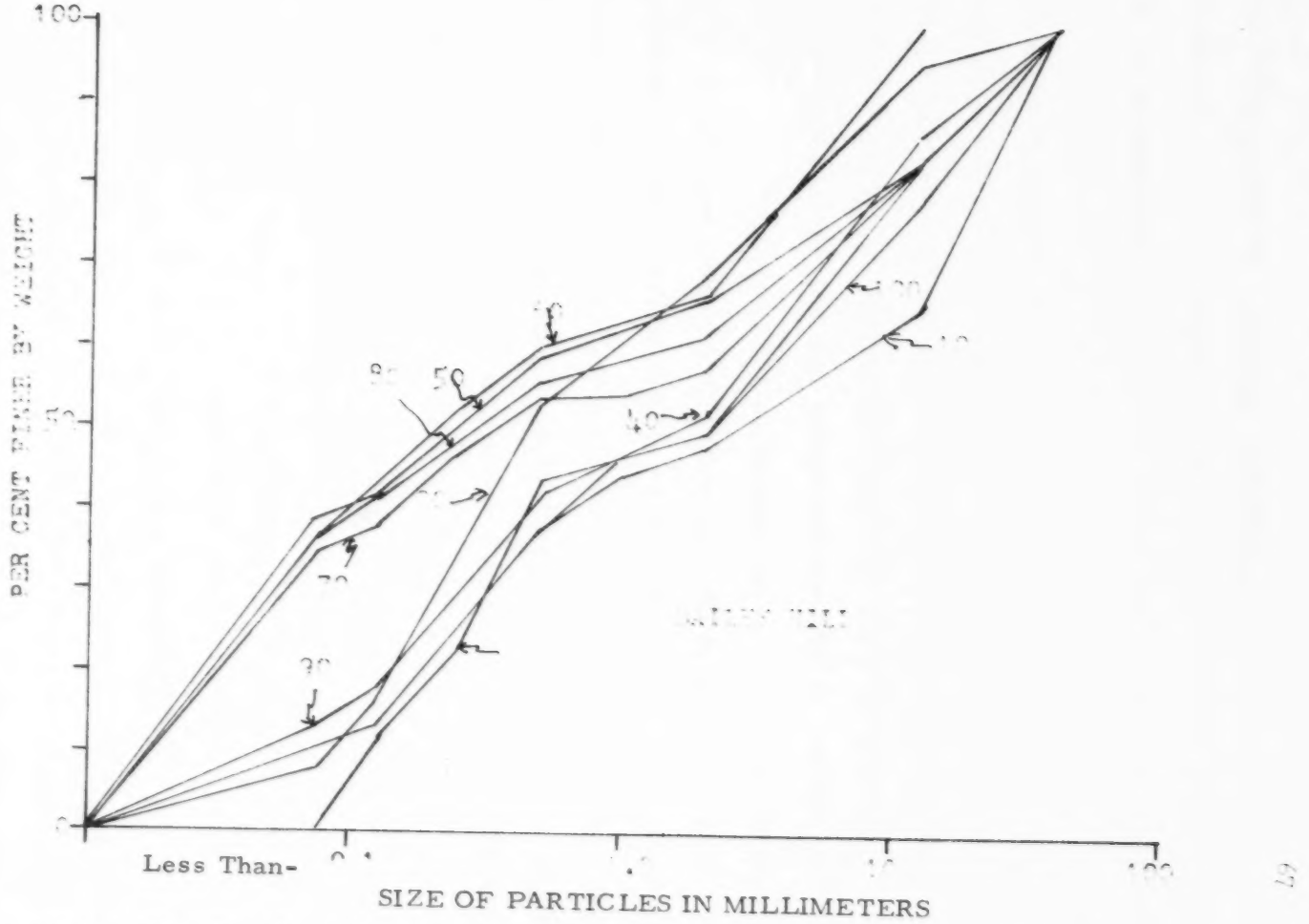

Figure 27. Results of mechanical analyses of sediments collected at 10 foot intervals from the highwater mark at Bailey Hill station.

is Aphanizomenon. A few Gloeotrichia, Anabaena, and Anacystis are often seen in grab samples. Small localized blooms of Anacystis were encountered in spring and early summer near shore in Zone III. Diatoms, Asterionella and Melosira, predominate during the winter.

Phinney and Peek (ibid) made cell counts of plankton during 1956 and 1957. They report a maximum count of 196,361 per ml for total phytoplankton off Eagle Ridge during August, 1956. Generally, for this sampling period, their counts were from 10 to 30 thousand per ml. Miller and Tash (1967) measured biomass of phytoplankton during 1965 and report a maximum value of about 26 mg/l for the last week of July (Figure 28).

Using the plankton net described in the methods section, we found seasonal variations in phytoplankton density similar to those reported by the previously cited authors. As shown in Figure 29, there was a wide range in observed density during any one sampling period. Aphanizomenon appeared to concentrate in certain areas, and these concentrations are undoubtedly a function of the previous history of wind velocities and directions. Superabundances were often located off Eagle Ridge, Shoalwater Bay, and in Howard Bay. Both bays were anaerobic on occasion late in the summer. These anaerobic conditions resulted at least in part from the decomposition of large masses of Aphanizomenon that accumulate in the bays.

As measured in inches of net plankton, Zone II had less variation in standing crop than Zones I and III. At times, areas along the north shore were almost free of algae. The interior of the marshes were relatively free of algae. No evidence was noted that bluegreen algae in the lake are toxic to fish. Both trout and other native species were abundant in areas of large Aphanizomenon blooms. Only during conditions of low concentrations of dissolved oxygen in bays were fish absent (Figure 9).

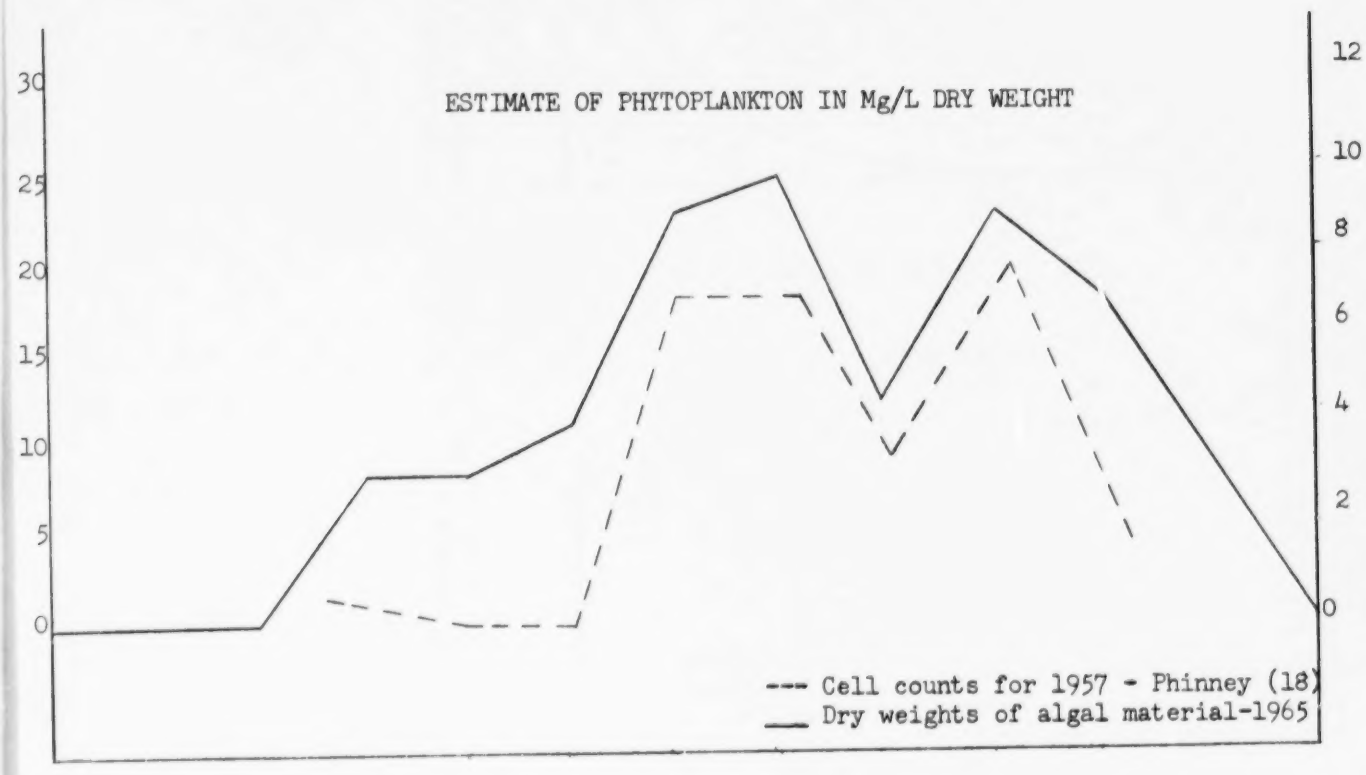

Figure 28. Seasonal biomass and algal cell counts in Upper Klamath Lake during 1965 and 1957, respectively. (Taken from Miller and Tash, 1967. Interim Report Upper Klamath Lake Studies. F.W.P.C.A.)

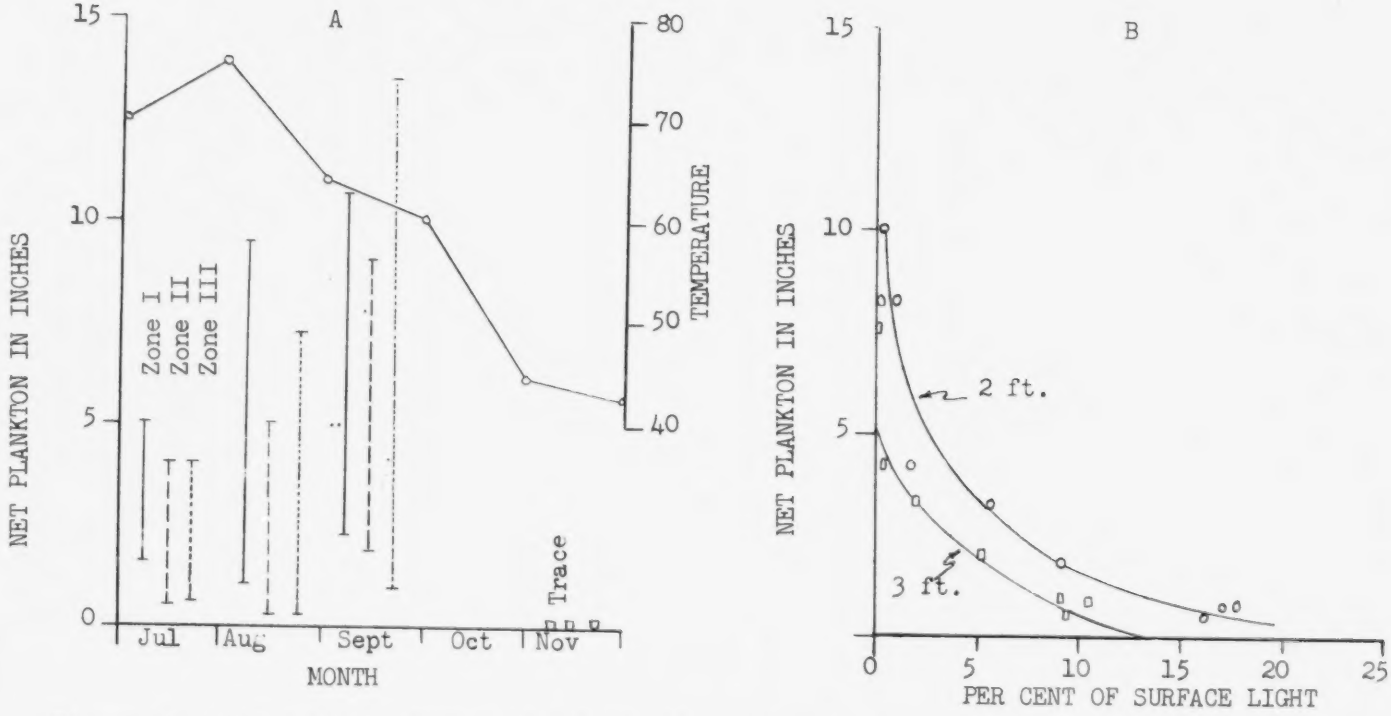

Figure 29. A-The concentration of net plankton and water temperature, and B- the relationship between the concentration of net plankton and light penetration in Upper Klamath Lake, 1965.

Zooplankton

Zooplankton were collected in Upper Klamath Lake from September, 1964, to July, 1965. Samples were taken near the surface and bottom with a Juday plankton trap except for the period from December, 1964 to March, 1965, when a cone type plankton net was used. Zooplankton were preserved in five percent formalin or 70 percent alcohol. Identification of Cladocera and Copepoda were either made or confirmed by Dr. Jerry Tash of the Federal Water Pollution Control Administration, Klamath Lake Project. Counts were made of the major groups in each sample.

The frequency of occurrence of the species in the three zones of the lake are given in Table XII. Frequency of occurrence generally corresponds with abundance. Daphnia schodleri, Chydorus sphaericus, and Leptodora kindti were the most abundant cladocerans. Diaptomus ashlandi and Cyclops spp. were the most abundant copepods. Rotifera were found only occasionally off Eagle Ridge. Ostracoda are of a sessile type not encountered very frequently in the zooplankton. Eurycercus, Ceriodaphnia, Diaphansoma, and Epischura were associated more with marsh areas than the open lake.

During July, 1913 when a survey of the lake was made by Kemmerer, et al. (1924), Copepoda were the most abundant of the zooplankton with Diaphansoma leuchtenbergianum and Diaptomus ashlandi listed as the two species present. No mention is made of Daphnia which is now the most abundant single genus.

Table XIII lists the average number of Daphnia and Copepoda near the survace and bottom in the three zones. By number, Daphnia were slightly more abundant than copepods; however, in biomass this difference is undoubtedly more pronounced. Since the Daphnia were almost exclusively one species, D. schodleri, the data suggest that they are stratified toward the surface. The

TABLE XII. THE RELATIVE FREQUENCY IN PERCENT OF ZOOPLANKTON SPECIES COLLECTED IN SURFACE, BOTTOM, AND ALL SAMPLES IN THE THREE ZONES OF UPPER KLAMATH LAKE (1964-65).

	Zone I			Zone II			Zone III		
	Sur.	Bot.	All	Sur.	Bot.	All	Sur.	Bot.	All
CLADOCERA									
Daphnia schodleri	100	100	100	100	100	100	95	100	98
Daphnia galeata	14	27	16	41	19	19	15	26	17
Daphnia rosea	0	0	0	0	0	0	5	0	2
Leptodora kindti	57	45	33	76	50	48	40	53	32
Eurycercus lamellatus	7	0	7	0	0	0	5	5	4
Eurycercus glacialis	0	0	0	0	0	0	5	0	2
Bosmia longirostris	7	0	2	6	12	6	25	21	30
Alona affinis	0	9	2	6	0	4	0	0	0
Chydorus sphaericus	78	91	63	71	88	71	65	58	66
Ceriodaphnia quadrangula	14	9	9	0	6	2	5	0	4
COPEPODA									
Diaptomas ashlandi	93	91	95	100	100	98	80	95	85
Diaptomas leptopus	7	0	2	6	0	2	0	0	0
Diaptomas clavipes	0	0	0	0	0	0	0	0	2
Diaptomas lintoni	0	0	0	0	0	0	10	0	4
Cyclops bicuspidatus thomasi	57	64	72	53	62	64	40	53	55
Cyclops vernalis	43	36	23	35	44	48	55	63	40
Diaphansoma brachyurum	0	36	12	12	6	7	25	26	19
Epischura nevadensis	28	18	14	0	6	4	15	21	11
Canthocampus staphylinoides	0	0	2	6	0	4	5	0	2
Eucyclops agilis	0	9	2	0	0	0	5	5	2
Macrocyclops albidus	0	9	5	0	0	6	15	0	19
OSTRACODA	14	18	7	24	12	8	20	21	11
ROTIFERA	0	0	0	6	6	4	0	0	0
NUMBER OF SAMPLES	14	11	43	17	16	52	20	19	47

TABLE XIII. THE AVERAGE NUMBER PER 10 LITER PLANKTON TRAP SAMPLE OF DAPHNIA AND COPEPODA IN THE THREE ZONES DURING AUGUST AND OCTOBER, 1964, AND JUNE, 1965.

Zone	I		II		III	
Depth	S	B	S	B	S	B
DAPHNIA						
Mean	183	105	296	129	243	88
Std. Er.	523	338	652	448	874	23
N.	8	8	14	14	14	14
COPEPODA						
Mean	76	76	71	128	184	122
Std. Er.	20	27	11	19	94	30
N	8	8	14	14	14	14

Copepoda group is from two to four species; consequently, nothing can be determined for vertical stratification. Copepods do appear to be more abundant in Zone III than in the other two.

Seasonally, the number per sample of Daphnia and Copepoda did not change very much. Gravid females were abundant in all samples.

Benthos

During 1964-65 one hundred seven Ekman Dredge samples (0.25 sq. ft.) were taken of soft sediments and sieved with a U. S. Standard No. 32 screen. Some organisms were taken by hand from rocks, limbs, and submerged and emergent plants. Macroinvertebrates were fixed in 10 percent formalin and preserved in 70 percent alcohol. Organisms that could be seen with the unaided eye were picked from small aliquots of samples spread out in white pans under bright light.

The macroinvertebrates collected in Upper Klamath Lake in 1964-65 are tabulated in Table XIV. The organisms taken were those available to capture by the technique used in the habitats sampled. These techniques were probably not adequate for representative sampling of Coleoptera, Hemiptera, and Odonata, because of the ability of these organisms to swim rapidly and thus avoid capture by dredge or hand.

Previous to this study, no known attempt had been made to determine the kinds of macroinvertebrates inhabiting Upper Klamath Lake. Davis, Jewett, and Mote (1939) and Bonnell and Davis (1942) reported on a midge, Chironomus utahensis, which was a nuisance around the lake. According to the former report, there were an estimated 542,080,000,000 larvae present in Upper Klamath Lake in 1932. As a point of comparison, we estimated 438 billion

TABLE XIV. BENTHIC MACROINVERTEBRATES COLLECTED IN UPPER KLAMATH LAKE, OREGON, 1964-66.

OLIGOCHAETA

HIRUDINEA
- Glossiphonidae
  - *Glossiphonia* sp.
  - *Helobdella* sp.
- Erpobdellidae
  - *Dina* sp.

POLYCHAETA
- Sabellidae
  - *Manayunkia speciosa*

GASTROPODA
- Physidae
  - *Physa* sp.
- Lancidae
  - *Lanx klamathensis*
- Lymnaeidae
  - *Lymnaea palustris*
- Planorbidae
  - *Heliosoma subcrenatum*
  - *Parapholyx effusa*
  - *Promenetus* sp.
- Valvatidae
  - *Valvata lewisi*
- Bulimidae
  - *Amnicola seminalis*
  - *Amnicola turbiniformis*
  - *Pyrgulopsis archimedis*
  - *Fluminicola seminalis*

PELECYPODA
- Unionidae
  - *Anodonta* sp.
- Sphaeriidae
  - *Sphaerium* sp.
  - *Pisidium* sp.

DECAPODA
- Astacidae
  - *Pacifastacus klamathensis*

AMPHIPODA
- Talitridae
  - *Hyalella azteca*
- Gammaridae
  - *Gammarus lacustris*

TABLE XIV CONTINUED. BENTHIC MACROINVERTEBRATES COLLECTED IN UPPER KLAMATH LAKE, OREGON, 1964-66.

ISOPODA
- Sphaeromidae
  - *Asellus tomalensis*

ODONATA
- Lestidae
  - *Archilestes* sp.
- Coenagrionidae
  - *Enallagma* sp.
  - *Ischnura* sp.
- Aeshnidae
  - *Aeshna* sp.

TRICOPTERA
- Phryganeidae
  - *Phryganea cinera*
- Hydropsychidae
  - *Hydropsyche californica*
- Psychomyiidae
  - *Psychoglypha* sp.
- Limnephilidae
  - *Limnephilus* sp.
  - *Dicosmoecus* sp.
- Leptoceridae
  - *Mystacides alafimbriata*
  - *Mystacides sepulchralis*
  - *Oecetis inconspicua*

EPHEMEROPTERA
- Ephemerellidae
  - *Ephemerella lodi*
- Caenidae
  - *Caenis* sp.

COLEOPTERA
- Haliplidae
  - *Haliplus* sp.
- Gyrinidae
  - *Gyrinus* sp.

HEMIPTERA
- Gerridae
- Notonectidae
- Corixidae

DIPTERA
- Culicidae
  - *Chaoborus* sp.

TABLE XIV CONTINUED. BENTHIC MACROINVERTEBRATES COLLECTED IN UPPER KLAMATH LAKE, OREGON, 1964-66.

DIPTERA (Cont.)
- Tendipedidae
  - *Tendipes* spp.
  - *Glyptotendipes* spp.
  - *Tanytarsus* spp.
  - *Harnischia* sp.
  - *Cricotopus* sp.
  - *Calopsectra* spp.
  - *Procladius* sp.
  - *Pentaneura* sp.
  - *Anatopynia* sp.

(about 600 tons) of midge larvae by extending our average number per sample of all samples reported in Table XV out to 134 square miles. A species of the Tendipes (Chironomus) plumosus type, similar in appearance and biology to the C. utahensis reported as causing a nuisance in the 1930's, is one of the more abundant species in the lake at present, but whether it is the same species that was present in 1932 was not determined.

In habitats that were sampled from the boat with an Ekman dredge, Oligochaeta were most frequently occurring, most numerous and represented the largest proportional biomass (Table XV). Proportionally, in numbers and biomass, worms were generally followed by leeches, midges, clams and snails except in Zone II where midges were less abundant. Zone III had the greatest variety of species and the greatest mean standing crop. No attempt was made to identify the species of Oligochaeta; however, it is believed that they were predominantly of the Tubifex and Limnodrilus types with some Lumbricus, which because of their large size, greatly distorted biomass measurements in respect to numbers. Stylarus was quite common in samples scraped from rocks.

Leeches represented the second largest biomass. Helobdella and Glossiphonia are found over most of the lake in about equal numbers. Dina which is large and constitutes an important food for trout is more often found near shore or in the marsh areas. Other unidentified leeches were found on the bottoms of rocks in shallow water. Helobdella and Dina were observed to prey on worms, midges, and injured amphipods.

A polychaet worm, Manayunkia speciosa, was collected from regions with peat bottoms in Zone I and Agency lake resulting in a significant extension of range for this species (Hazel, 1966).

TABLE XV. AVERAGE NUMBER AND WET WEIGHT PER SQUARE METER AND FREQUENCY OF OCCURRENCE OF BENTHOS BY ZONE DURING 1964 AND 1965.

	ZONE I			ZONE II			ZONE III		
No. of Samples	38			29			40		
	No/M^2	Gr/M^2	Freq	No/M^2	Gr/M^2	Freq	No/M^2	Gr/M^2	Freq
Oligochaeta	4655	25.95	1.00	3868	45.51	0.93	7500	52.00	0.92
Hirudinea	1164	6.40	0.92	1466	4.68	0.93	2026	5.30	0.82
Diptera	1940	2.35	0.63	172	0.47	0.59	1681	2.04	0.38
Gastropoda	172	0.24	0.47	216	5.11	2.16	1379	0.47	0.30
Pelycepoda	948	0.96	0.32	1466	2.10	0.17	1164	0.90	0.22
Amphipoda	86	0.36	0.08	172	-	0.07	1940	-	0.12
Isopoda	P	-	-	P	-	-	1595	0.08	0.05
Tricoptera	1	0.01	0.12	P	-	-	172	0.07	0.15
Ephemeroptera	43	-	0.03	43	-	0.03	43	0.08	0.02
Odonata	P	-	-	P	-	-	P	-	-
Coleoptera	P	-	-	P	-	-	P	-	-
Hemiptera	P	-	-	P	-	-	P	-	-
Porifera	P	-	-	-	-	-	P	-	-
Polychaeta	P	-	-	-	-	-	-	-	-

Gastropoda were represented by eleven species some of which were found in only a few locations. Lanx klamathensis and Pyrgulopsis archimedis were found in large numbers on rocky beaches in Zone I. Valvata lewisi and Paraphlyx effusa were found on rocky beaches in Zone III. Heliosoma was taken consistently in deep water off Eagle Ridge and at other deep water locations in Zones II and III. The other species listed were found most frequently in or near marshes.

Unidentified clams, less than 5 mm in length were collected in all zones. Larger clams had more restricted distributions. Sphaerium and Pisidium were abundant along the north shore and near the mouth of Williamson River. Anodontia were abundant in Zone I, but were found in all zones.

Pacifasticus klamathensis was collected only near the mouth of Williamson River.

Hyalella azteca was abundant in shallow water. Gammarus sp. was collected only once in Hanks Marsh.

Although the isopod, Asellus tomalensis, was collected in rock and sand beaches in all zones, it was abundant only in Zone III.

Caddis flies were numerous during the warm months. Mystacides was the most abundant genera especially in rocky shoreline areas. Dicosmoecus sp. was found only at Housepit Beach. Phyganea cinera was collected in marsh areas and at the mouth of Williamson River. Limnephilus was abundant in marshes and along beaches in Zone III.

Ephemerella lodi was collected only once near Pelican Marina. Caenis was present but not abundant in all zones.

Chaoborus was found only in Zone III and then rarely. Tendipes, Glyptotendipes, and Procladius were the most abundant midge genera. Tendipes and

Procladius occurred most frequently in soft sediments. Glyptotendipes was associated with beach areas.

Of the 107 benthos samples, 79 (Zone I, 26; II, 21; III, 32) were taken of the ooze that covers the bottom at distances greater than about 100 feet from shore or edges of marsh areas. By number and biomass Oligochaeta and Hirudinea (Helobdella and Glossiphonia) were the representative animals in this ooze. Midge larvae were frequently collected during the winter, spring, and early summer in Zones I and II, and snails were often collected in Zone II. Most other organisms collected were in low numbers and in Zone III (Table XVI). Worms and leeches were most abundant during November and December, but this may be an artifact due to their larger size at this time of year. Smaller organisms, which are most abundant during summer and fall, pass through the No. 32 screen. The variety of organisms collected in the ooze was greatest in Zone III in July of 1965. Many of these samples were taken off North Shore which is a slightly different habitat than other sampled locations.

It was made evident by the survey of benthos that in the expanse of sediments underlying open water the community of macroinvertebrates is largely one of oligochaetes and leeches of the family Glossiphoniidae. Lesser populations of midges, snails, and clam are present especially in the winter and spring.

Near shore and in marshes there is a greater variety of species with fewer oligochaetes and leeches. Figure 30 illustrates a distribution of six species of Tendipedidae and a leech, Helobdella, in a wave-washed beach at Bailey Hill. Sediments on this beach grade from cobble through granular and graded sands to a diatomaceous ooze at a depth of eight feet (Figure 27).

TABLE XVI. THE AVERAGE NUMBER OF BENTHOS PER EKMAN DREDGE SAMPLE BY MONTH OF COLLECTION AND ZONE IN THE DIATOMACEOUS OOZE THAT COVERS MOST OF THE BOTTOM.

	Month	7-64	8-64	9-64	10-64	11-64	12-64	3-65	7-65
	Zone								
OLIGOCHAETA	I	28.17	181.00	-	-	128.00	238.67	79.67	44.00
	II	71.50	63.20	-	284.00	87.33	100.00	95.67	-
	III	176.80	70.50	279.00	420.25	289.00	60.50	154.78	117.50
HIRUDINEA									
Helobdella	I	22.00	24.00	-	-	49.00	29.67	8.83	31.00
	II	21.50	7.40	-	17.25	41.67	39.00	12.00	-
	III	9.40	2.50	8.00	27.25	15.00	19.00	20.56	87.00
Glossiphonia	I	8.33	3.50	-	-	28.00	64.67	8.50	3.67
	II	-	1.60	-	62.00	15.67	30.00	12.50	-
	III	4.00		6.67	70.75	45.00	1.00	11.22	2.33
Dina	I	0.83		-	-				0.33
	II			-					-
	III			0.33	0.25			0.11	0.17
GASTROPODA	I			-	-			1.67	0.50
	II			-	0.50	0.67		1.17	-
	III		1.00		1.75		5.50		12.67
PELYCEPODA	I	0.67			-			10.00	1.67
	II				-				-
	III			0.25			4.50	0.11	37.00
DIPTERA	I	0.33	0.75	-	-	2.00	12.67	15.00	15.83
Tendipedidae	II	0.50	2.40	-	1.50	1.33		1.67	-
	III		0.50		1.75		32.50	0.96	51.23

TABLE XVI CONTINUED. THE AVERAGE NUMBER OF BENTHOS PER EKMAN DREDGE SAMPLE BY MONTH OF COLLECTION AND ZONE IN THE DIATOMACEOUS OOZE THAT COVERS MOST OF THE BOTTOM.

	Month	7-64	8-64	9-64	10-64	11-64	12-64	3-65	7-65
	Zone								
Chaoborinae	I								
	II								
	III		0.50		0.75				
EPHEMEROPTERA	I			-	-			0.17	
Caenis	II			-					-
	III								4.00
TRICHOPTERA									
	I			-	-				0.50
Limnephilus	II			-					-
	III								0.17
	I								
Phryganea	II								
	III								0.83
AMPHIPODA									
	I			-	-			0.33	
Hyalella	II			-					-
	III								1.00
ISOPODA									
	I								
Asellus	II								0.67
	III								

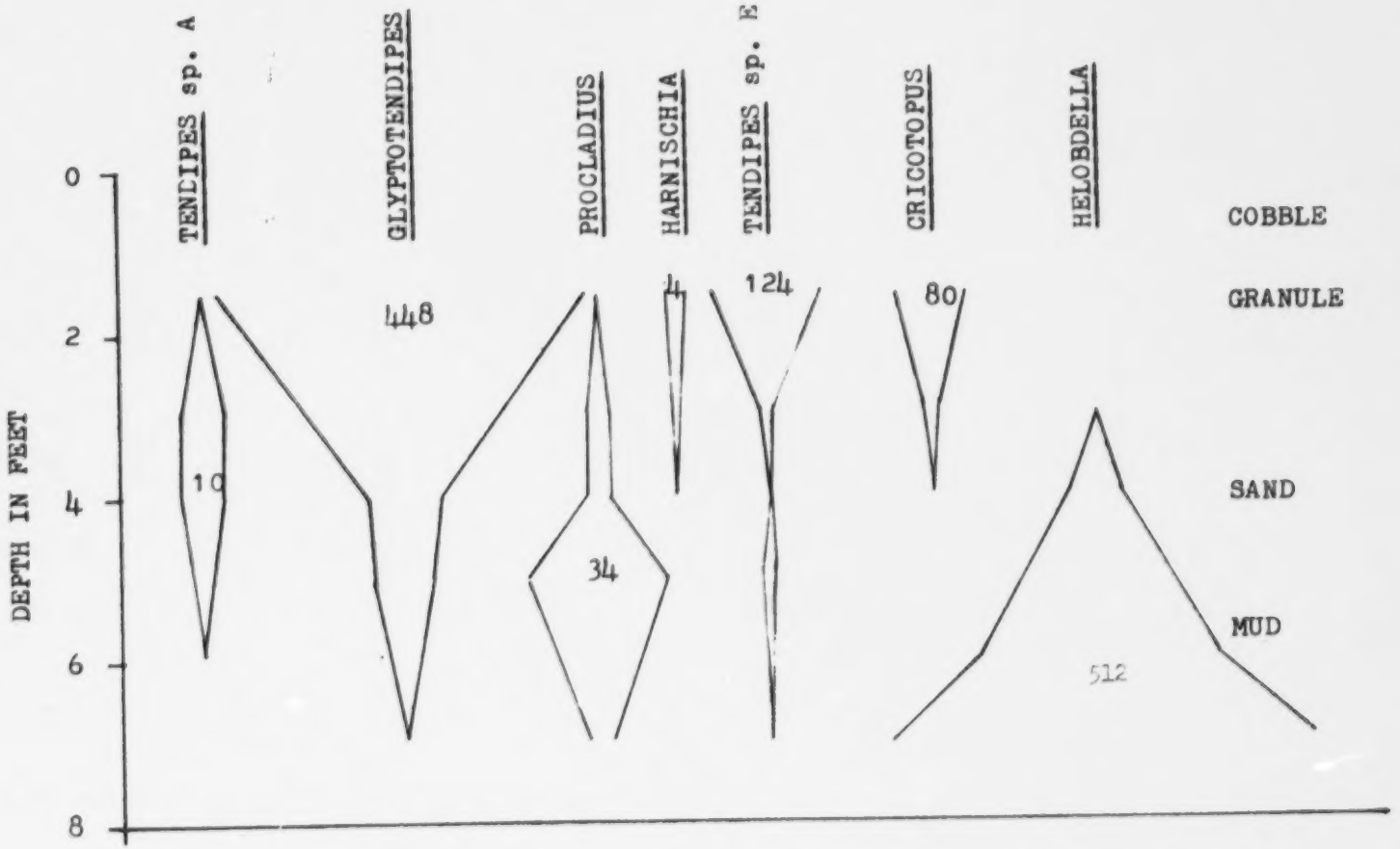

Figure 30 . Distribution of six species of Tendipedidae and one leech at Bailey Hill in respect to depth and substrate type (June 4, 1965).

Preferences either for depth, substrate type, and community relationships are implied by this observation.

Tendipes sp. (A), Procladius sp. and Helobdella sp. are found in significant numbers in most of the lake's sediments. The other species listed in Figure 30 are associated with shallower water and sand to cobble substrates.

FISH INVESTIGATIONS

Species Composition

The exploratory survey of 1964 (July 9 through December 27) caught 9,561 fish in 392 individual sets (average 22 hours per set for a total of 8,624 hours) on 60 fishing days. The major results obtained from this preliminary investigation were: (1) seasonal movements of rainbow trout, yellow perch and brown bullheads existed (Table 17); (2) that incoming waters from springs and streams might influence the distribution of fishes (Table 18); (3) that some fishes such as the tui chub and brown bullhead preferred bays to the open lake (Table 19); (4) that a differential picture of relative distribution and abundance of fishes of Klamath Lake could be produced (Figure 31).

During the comprehensive study from June 30, 1965 to December 12, 1965 446 individual net sets fished a total of 9,668 hours (average 20 hours per set) on 58 different days. A total of 24,440 fish was caught including 15 recognizable species in eight different families (Table 20). Several intergrades of the three species of suckers were observed along with a possible hybrid sculpin resembling Cottus princeps.

The relative abundance of each species or family was similar to that of 1964 except for the yellow perch and sculpins which reversed positions in 1965 (Figure 31). The blue chub and tui comprised 93% of the total catch while the other 13 species contributed only 7%.

TABLE 17. Fish per net set by zones (north, middle, south) and months, Upper Klamath Lake, 1964.

	July			August			September		
	North # Sets 13	Middle # Sets 15	South # Sets 4	North # Sets 26	Middle # Sets 33	South # Sets 19	North # Sets 28	Middle # Sets 20	South # Sets 8
	Avg/set	Avg/set	Avg/set	Avg/set	Avg/set	Avg/set	Avg/set	Avg/set	Avg/set
Blue chub	16.2	17.6	14.7	10.4	31.4	10.1	5.0	30.1	8.0
Tui chub	11.2	18.0	14.0	5.1	11.5	9.2	2.8	4.2	6.1
Brown bullhead	2.8	0	0	13.4	0	0	1.9	0.1	0
Yellow perch	0.4	0.3	0	1.7	0	*	0.3	0	0
Sculpins	*	0.1	0.7	0.2	*	0.2	0.1	0.1	0
Trout	0.1	0	0	0	*	0	*	0	0
Lamprey	0	0	0	0	*	0	0	0	0
Pumpkinseed	*	0	0	0.1	*	0	0	0	0
Suckers	0	0	0	0.1	0	*	*	*	0

* less than 0.1

** one brown trout.

October			November			December		
North # Sets	Middle # Sets	South # Sets	North # Sets	Middle # Sets	South # Sets	North # Sets	Middle # Sets	South # Sets
48	35	none	8	24	24	8	24	47
Avg/set	Avg/set	Avg/set	Avg/set	Avg/set	Avg/set	Avg/set	Avg/set	Avg/set
8.5	34.8	---	2.6	13.1	8.4	1.0	23.7	9.5
6.3	18.5	---	1.0	7.4	3.6	1.0	4.9	1.8
1.3	0.1	---	*	0.1	0	0	0	*
1.1	1.9	---	0.8	1.0	*	0	*	0
0.1	0.2	---	0.3	0.3	*	0	0.1	0
*	*	---	0	0.2	0	0**	0.1	0.2
*	0	---	0	0.2	0	0	0	0
0	0	---	0	0.1	0	0	0	*
*	0.2	---	0	0.3	0	0.2	*	0

TABLE 18. FISH CAPTURED AND NUMBER OF FISH PER SET IN AREAS UNDER THE INFLUENCE OF INCOMING WATER AND IN OTHER AREAS, UPPER KLAMATH LAKE, 1964.

	Incoming water influence (# Sets 156)		Other (# Sets 141)	
	Avg/set	# Fish	Avg/set	# Fish
Blue chub	14.3	2228	13.8	1952
Tui chub	9.7	1510	6.0	835
Brown bullhead	0.9	142	2.7	377
Yellow perch	1.2	192	0.1	14
Trout	0.2	27	0	0
Sculpins	0.2	25	0.1	17
Pumpkinseed	--	4	--	3
Lamprey	--	3	--	1
Suckers	0.1	23	--	3

TABLE 19. FISH CAPTURED AND NUMBER OF FISH PER SET, OPEN LAKE COMPARED WITH BAYS, UPPER KLAMATH LAKE, 1964.

	Open Lake (# Sets - 155)		Bay (# Sets - 94)	
	Avg/set	# Fish	Avg/set	# Fish
Blue chub	16.8	2614	17.9	1681
Tui chub	5.9	920	12.1	1137
Brown bullhead	.7	113	4.2	395
Yellow perch	.2	24	1.5	142
Trout	.2	23	.1	15
Sculpins	--	9	.1	14
Pumpkinseed	0	0	--	6
Lamprey	--	--	--	1
Suckers	0	0	.1	14

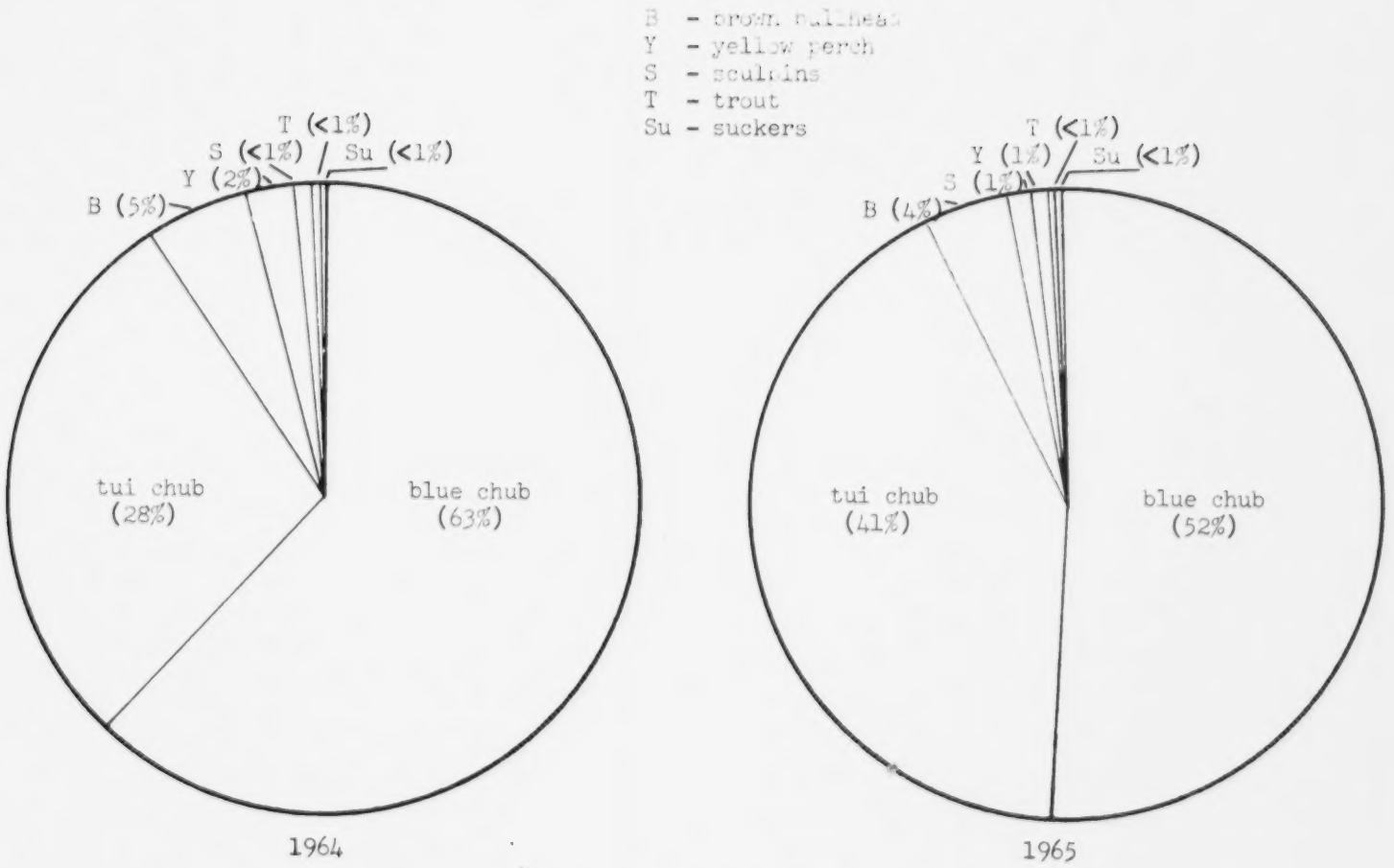

Figure 31: The relative abundance of fishes in Upper Klamath Lake, Oregon, illustrated by percentages by total number of fish caught in 392 net sets in 1964 and 446 net sets in 1965.

TABLE 20.

LIST OF THE FISHES OF UPPER KLAMATH LAKE, OREGON

Petromyzonidae	
Klamath brook lamprey	*Lampetra* sp.
Pacific lamprey	*Lampetra tridentata* (Gairdner)
Salmonidae	
Rainbow trout	*Salmo gairdneri* Richardson
Brown trout	*Salmo trutta* Linnaeus
Brook trout	*Salvelinus fontinalis* (Mitchill)
Cyprinidae	
Blue chub	*Gila bicolor* (Girard)
Tui chub	*Siphateles bicolor* (Girard)
Catostomidae	
Lost River sucker	*Catostomus luxatus* (Cope)
Klamath largescale sucker	*Catostomus snyderi* Gilbert
Shortnose sucker	*Chasmistes brevirostris* Cope
Ictaluridae	
Brown bullhead	*Ictalurus nebulosus* (LeSueur)
Centrarchidae	
Pumpkinseed	*Lepomis gibbosus* (Linnaeus)
Percidae	
Yellow perch	*Perca flavescens* (Mitchill)
Cottidae	
Marbled sculpin	*Cottus klamathensis* Gilbert
Klamath Lake sculpin	*Cottus princeps* Gilbert
Slender sculpin	*Cottus tenuis* (Evermann and Meek)
Cottus sp.	

As the 1964 data implied, the rainbow trout displayed a seasonally or spatially regular distribution. (Figures 32 and 33) To a lesser extent, the brown bullhead (Figure 34 and 35) and the yellow perch (Figures 36 and 37) show this regularity.

Seasonal distribution is difficult to determine by gillnet data because activity (movement) is required of the fish before it is vulnerable to the nets. If temperature determines the activity of a fish, then the fish would be caught at a different rate each month even though the distribution of the population may not have changed.

Consequently, to compare monthly catches throughout the sampling period a conversion to percentage seemed necessary in order to minimize the bias of activity patterns on distribution. Thus, if we let all fish caught in the entire season equal 100%, then by dividing the total fish per hour per month by the total season's catch in fish per hour, the percentage contribution of each month's catch to the total catch is obtained. Likewise the percentage contribution of a zone for the season can be found by dividing the total catch of a particular zone for the season by the total season's catch. Also, if the total monthly catch is interpreted to be equal to 100%, by dividing the total catch per hour of a zone by the total monthly catch, the percentage contribution of each zone per month is obtained. Tables 21 and 22 summarize these data for the tui chub and the blue chub.

Size Composition

The size range of the tui chub and blue chub taken in each of the four mesh sizes is shown in Table 23. Size overlap in the range of catch occurred only between the 2 1/4 and 3-inch meshes. The overlap is probably significant enough that the two mesh sizes could be added together and considered as one

Figure 32. Catch of rainbow trout, Salmo gairdneri, along rock shoreline, Upper Klamath Lake, Oregon, 1965

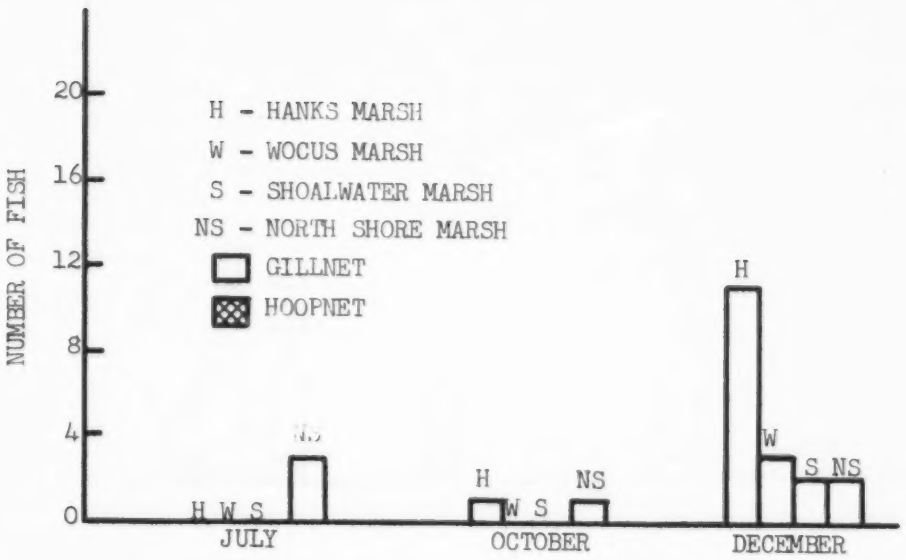

Figure 33. Catch of rainbow trout, Salmo gairdneri, along marsh shoreline, Upper Klamath Lake, Oregon, 1965.

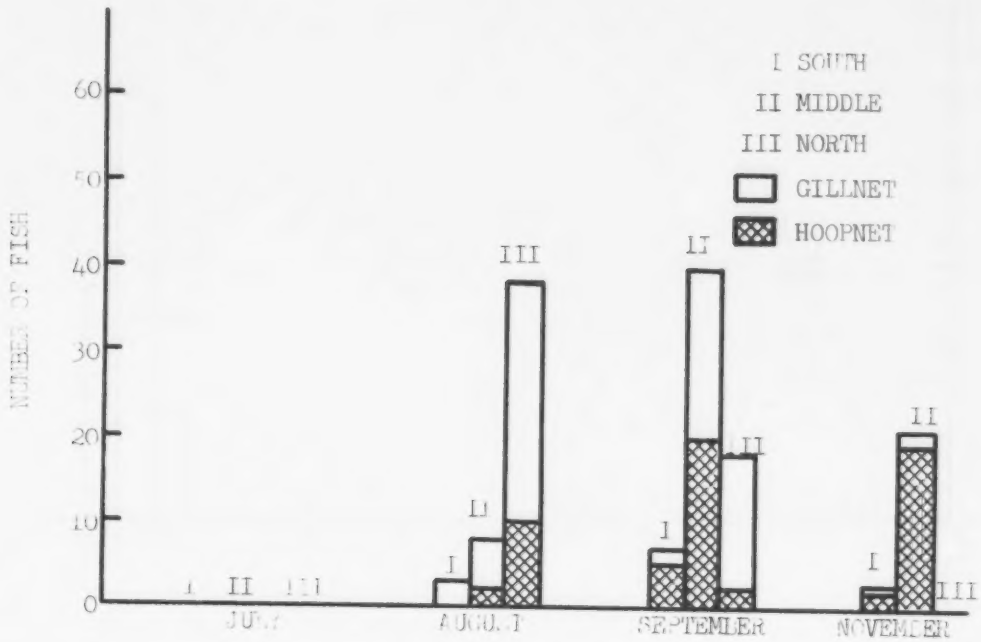

Figure 34. Catch of yellow perch, Perca flavescens, Upper Klamath Lake Oregon, 1965

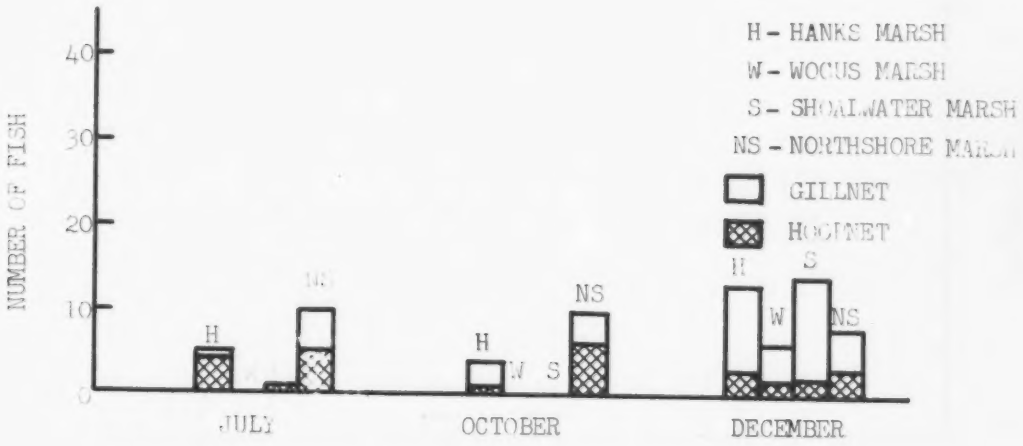

Figure 35. Catch of yellow perch, Perca flavescens, Upper Klamath Lake Oregon, 1965

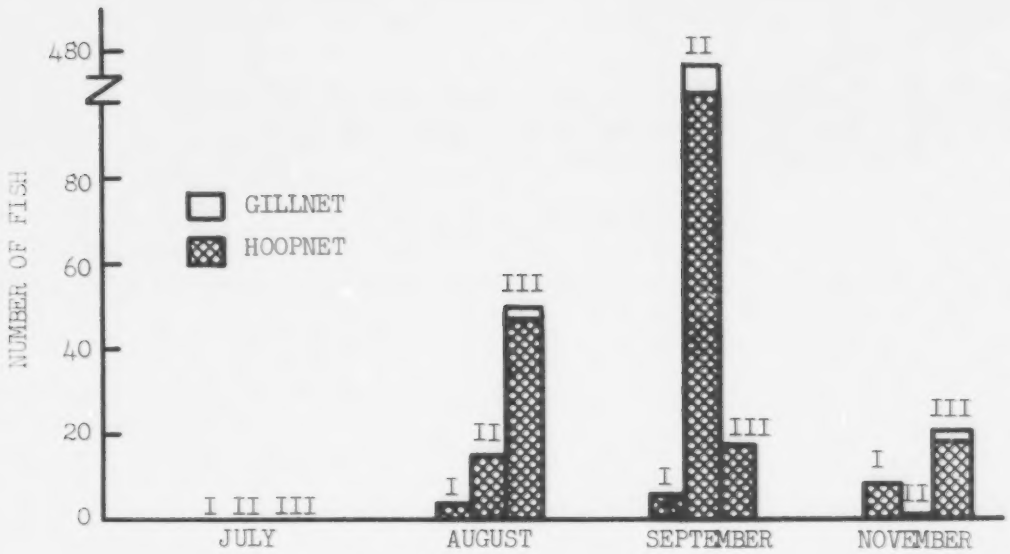

Figure 36. Catch of brown bullheads, Ictalurus nebulosus, along rock shoreline, Upper Klamath Lake, 1965.

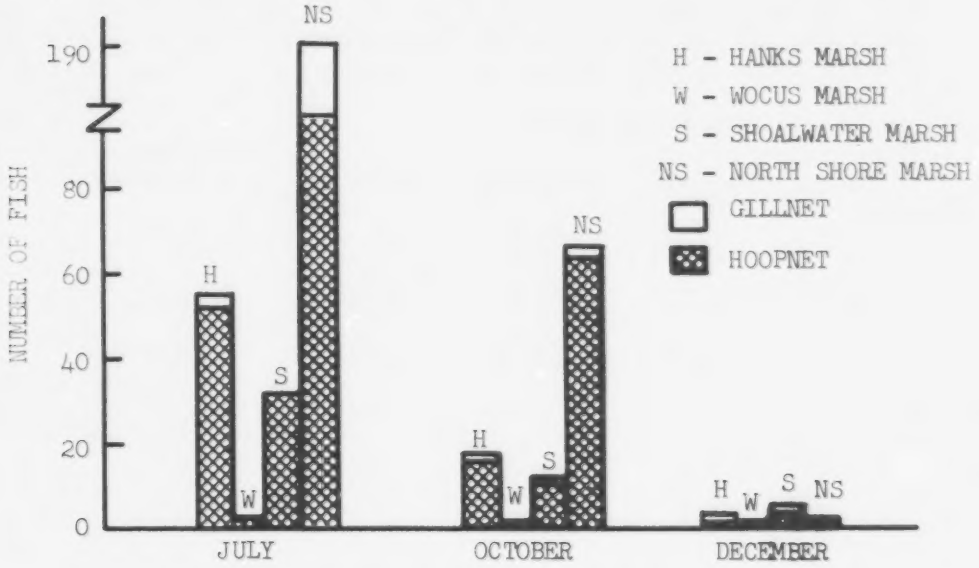

Figure 37. Catch of brown bullheads, Ictalurus nebulosus, Upper Klamath Lake, Oregon, 1965

TABLE 21. THE PERCENTAGE CONTRIBUTION OF EACH ZONE TO THE MONTHLY AND TOTAL CATCHES OF TUI CHUBS (Siphateles bicolor) UPPER KLAMATH LAKE, OREGON 1965.

	SAMPLING PERIOD				
Zone	July	August	September	December	Percentage of catch by Zone
I	24.0	43.5	36.6	28.7	38.3
II	23.6	8.7	27.6	47.5	19.8
III	52.4	47.8	35.8	23.8	43.7
Percentage of season's catch by month	21.5	47.8	19.6	11.1	

TABLE 22. THE PERCENTAGE CONTRIBUTION OF EACH ZONE TO THE MONTHLY AND TOTAL CATCHES OF BLUE CHUBS (Gila bicolor) UPPER KLAMATH LAKE, OREGON 1965.

	SAMPLING PERIOD				
Zone	July	August	September	December	Percentage of catch by Zone
I	41.6	46.7	32.5	24.8	37.8
II	31.4	20.4	31.9	56.4	32.4
III	27.0	32.8	35.6	18.8	29.8
Percentage of season's catch by month	34.8	20.5	32.3	12.4	

TABLE 23. Size range of chubs captured in experimental gill nets, Upper Klamath Lake, Oregon

Stretch mesh size in inches	Fork length in Millimeters	
	Blue chub	Tui chub
1.25	114 - 148	102 - 134
1.75	158 - 209	127 - 172
2.25	228 - 298	201 - 266
3.00	272 - 343	237 - 287

mesh size, but for this analysis they will be considered individually.

The size composition of the season's catch of tui chubs along the rock shoreline for the four sizes of mesh (stretched measure) utilized in sampling was: 28.3% (3-inch); 12.4% (2 1/4-inch); 29.2% (1 3/4-inch) and 30.1% (1 1/4-inch), which indicates an almost equal abundance of sizes at least on a seasonal basis. (Only 40 feet of 2 1/4-inch mesh was used, which results in its low contribution to the catch as compared with 170 feet for each of the other mesh sizes.

A slight discrimination among zones was observed by the four size-groups of tui chubs sampled. The larger fish were found mainly in Zone I (44.9% in 3-inch mesh and 45.4% in 2 1/4-inch mesh) while the medium size-group was found mainly in Zone II (43.4%), and the smallest fish almost equally in all three Zones (I-28.0%; II-34.0%; III-38.0%).

The monthly distribution data show evidence of recruitment into certain mesh sizes, with the catch in the 1 1/4-inch mesh showing a substantial increase in August and a decrease in September and November, while the catch in the 1 3/4-inch mesh showed a substantial increase from August to September.

The size composition of the rock-shoreline catch of blue chubs shows that 45.2% of the fish were taken in the large 3-inch mesh of the experimental gillnets while each of the three other meshes, 2 1/4, 1 3/4, and 1 1/4, contributed only 16.3%, 20.3% and 18.2% respectively to the catch.

Spatially the various sizes of blue chubs did not appear to discriminate among zones except possibly the fish taken in the 1 1/4-inch mesh which appeared more frequently in the Zone II (43.1%) catch than in the catch of the other two zones. The monthly contribution of each mesh size to the

season's catch remained virtually the same for the 3 and 1 3/4-inch mesh through the four months of sampling, while the 2 1/4-inch mesh contributed less as the season progressed. The 1 1/4-inch mesh was the only mesh size to increase its monthly contribution to the season's catch from July (12.9%) to November (33.9%) indicating recruitment into this mesh size.

Species Distribution

Distribution according to type of shoreline. Data gathered for the entire season on the shoreline distribution of fishes are summarized in Table 24. "Preferences" for certain habitats are indicated by most of the fishes. Table 24 shows 4.4% and 7.1% of the total catch of brown bullheads and yellow perch were taken in the midlake areas, indicating that these species remain relatively close to the shore. The trout were the only fish which failed to show any shoreline "preference" even though most were taken during the summer months along the northern marsh shoreline area. The uniformity of trout distribution indicates that other factors are involved in determining their distribution. Probably factors such as water quality and food availability exerted more influence on the distribution of trout than the type of shoreline. Chubs were abundant in midlake (Table 25).

Suckers were not taken in a large enough quantity to indicate a "preference" for a shoreline habitat although beach siene hauls over rock (gravel) bottom areas caught many small suckers (2 - 6 inches).

The blue chub and sculpins show an apparent avoidance of the marsh shoreline as only 13.8% of the blue chub catch and 11.1% of the sculpin catch were caught there. Brown bullhead and yellow perch, however, were

TABLE 24. SHORELINE HABITAT PREFERENCE OF FISHES CAUGHT IN UPPER KLAMATH LAKE, OREGON 1965, SHOWN BY PERCENTAGE OF CATCH IN EACH HABITAT

Shoreline Habitat	Species						
	Blue Chub	Tui Chub	Brown Bullhead	Yellow Perch	Sculpins	Trout	Suckers
Rock	43.1	42.4	39.3	42.9	62.3	33.3	57.8
Marsh	13.8	28.8	56.3	50.0	11.1	39.0	21.1
Midlake	43.1	28.8	4.4	7.1	26.6	27.7	21.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 25. MIDLAKE CATCH COMPOSITION FOR AUGUST AND SEPTEMBER 1965 (12 SETS OF FOUR GILLNETS, FISHED 306 HOURS) UPPER KLAMATH LAKE, OREGON.

Date	Number Net Sets	Zone	Species: Rainbow Trout	Yellow Perch	Brown Bullhead	Sculpins	Tui Chub	Blue Chub
Aug. 10-13	4	II	0	0	0	2	627	737
	4	III	4	0	14	4	185	403
Sept. 15-17	2	II	1	1	0	0	107	553
	2	III	2	4	0	12	83	228

were caught more frequently along the marsh shoreline than along the rock shoreline or in the midlake area.

Distribution of tui chub. The percentage of the rocky shoreline catch in fish per hour of the tui chub increased from 21.5% in July to 47.8% in August and then decreased in September to 19.6% and to 11.1% in November, indicating a seasonal change in activity.

Spatially, Zone I, II, and III produced 38.3, 19.8 and 43.7% of the rocky shoreline catch respectively. Zone II contributed substantially to the catch only in November (47.5% of the monthly catch) while Zone I and III contributed almost equally in all months except July when Zone III had more than twice the catch of Zones I and II.

The percentage of the monthly catch taken in each zone gave an idea of the distribution of the species in the lake. The catch in Zone III showed a steady decline (52.4% in July to 23.8% in November) throughout the season in its percentage contribution to the monthly catch, while the catch in Zone II showed a decrease only in August to 8.7% and then increased substantially through September and November and provided almost one-half of the November catch. Zone I nearly doubled its contribution of July by November. Only in September did the fish seem to be nearly equally distributed throughout the three Zones, when Zones I, II and III contributed 36.7, 27.6 and 35.8% respectively.

The seasonal catch of tui chubs from the four different marshes indicated that the population of tui chubs along the marsh shoreline did not change much throughout the year; as measured by percentage of the catch (42.4% in July; 24.2% in October; and 33.4% in December). The large percentage in July was due possibly to fast growth that recruited fish

into the small meshes and to larger mature fish moving from spawning grounds. The marshes located within bays seem to be preferred by the tui chub as indicated by the consistency of catch for the three sampling months. Wocus Marsh was the most consistent producer with Shoalwater, North Shore and Hanks marshes following in that order, except during the month of October, when Shoalwater produced only 0.3 fish per hour, which was well below the almost 5 per hour in July and December.

During the August sampling period more tui chubs were caught in the midlake area of Zone II than Zone III. However, during the September sampling period there was little evidence of a zonal preference.

This could be a possible indication of movement by the tui chub to the midlake area (under certain conditions such as high winds) from the "preferred" shoreline areas.

Distribution of blue chub. Seasonally, two-thirds of the catch along rocky shorelines was taken in the months of July (34.8%) and September (32.3%) while the remaining one-third was divided between August (20.5% and November (12.0%)

The percentage contribution of Zone II to the monthly catch decreased by 11% from July (31.4%) to August (20.4%) but increased again in September (31.9%) and almost doubled in November (56.4%). Catches in Zone I and III did not follow a pattern similar to those of the tui chub. Zone I contributed 41.6% in July, 46.7% in August and then decreased in September (32.5%) and November (24.8%) while the Zone III catch increased through September (27.0% July; 32.8% August; 35.6% September) and fell off substantially in November to 18.8%. September was the only month in which fish were nearly evenly distributed over all three zones, the other months were all weighted

to one zone or another.

Essentially there was no difference in the geographical distribution of the blue chub during the 1965 sampling season. Zone I (37.8%) was only slightly favored over Zone II (32.4%) and Zone III (29.8%).

Almost 90% of the blue chubs caught along a marsh shoreline were taken in the months of July (46.5%) and October (43.2%). A definite decrease in the activity, as in November along the rocky shoreline, was shown in December when only 10.3% of the total season's catch was taken.

Individual marshes seemed to contribute according to their association with the lake proper. The pattern is almost the reverse of that of tui chub. In the case of the blue chub more fish were taken along marsh areas connected to the main lake (Hanks Marsh and North Shore Marsh) then the other two areas combined. Hanks Marsh contributed more than 45% of the total season's catch.

Blue chubs appear to be as plentiful in the middle of the lake as along the shoreline with the Zone II area during both the August and September sampling periods.

Ecological tolerance of blue and tui chub

The apparent wide ecological tolerance of the blue and tui chubs is substantiated by data from Klamath Lake. A significant correlation was not found between the numbers of chubs caught and the environmental factors measured. Only nearly complete lack of dissolved oxygen appeared to prevent blue and tui chubs from occupying all sections of the lake. These species were taken even in areas where dissolved oxygen was as low as 0.1 mg/l and scum of decaying algae existed. Capture of tui chubs under such dissolved

oxygen conditions is reported by Kimsey (1954) from Eagle Lake, California. In Klamath Lake only a single series of six nets, set in the anoxic waters of Wocus Bay, failed to catch a single cyprinid. Decaying organic matter, undoubtedly algae, was responsible for these extreme conditions in certain areas of the lake.

In an effort to determine the possible effects on distribution of tui and blue chubs of the many variables encountered, a step-wise regression analysis was instituted to eliminate variables of probable insignificance. All 31 factors measured do influence fish distribution to some degree but this computer analysis indicated that out of the 31 variables the linear combination of the first 10 entering variables$_1$ could have the greatest influence on the catch of blue chubs (Table 26). The other 21 were either masked or nonsignificant in their contribution.

The data for tui chubs show that only the first seven variables were above the cut-off of ± 2.00 for the Student's T (Table 27).

Many of the same variables entered in both cases, however, the order of appearance was not the same.

These data then indicate that the diver gill net accounted for the greatest variation in the blue chub catch, while the net plankton accounted for the greatest variation in the tui chub. This would then help substantiate a previously-made statement that the decrease in the September tui chub catch could be due to avoidance to an abundance of net plankton (algae) that was present during that sampling period.

This statistical analysis emphasizes the difficulty of correlating distribution of fishes with environmental factors. Many factors, environmental or otherwise, operating singly or in combination, including the

TABLE XXVI. RANKED LIST OF VARIABLES AS THEY ENTERED THE STEP-WISE REGRESSION ANALYSIS ("ORDER OF IMPORTANCE") FOR BLUE CHUB (*Gila bicolor*) IN UPPER KLAMATH LAKE, 1965.

Variable	Entering F Level	Entering Student's T	Correlation Coefficient
Diver Gill net	183.90	13.56	.54
Marsh Shoreline	43.10	-6.56	-.25
Floating Gill net	42.83	6.54	.04
Dissolved Oxygen "In"* Surface	22.82	4.78	.21
Methyl Orange Alkalinity "In"*	9.36	3.06	-.15
Zone II	9.57	3.09	.05
Net Plankton "Out"**	8.68	2.95	.15
Methyl Orange Alkalinity "Out"	5.81	2.41	.03
Time	5.6	2.37	-.02

*measurements taken when nets were placed into the water (mean time 1000 hrs)

**measurements taken when nets were removed from the water (mean time 1430 hrs)

TABLE XXVII. RANKED LIST OF VARIABLES AS THEY ENTERED THE STEP-WISE REGRESSION ANALYSIS ("ORDER OF IMPORTANCE") FOR TUI CHUB (Siphateles bicolor) IN UPPER KLAMATH LAKE, 1965.

Variable	Entering F Level	Entering Student's T	Correlation Coefficient
Net Plankton "In"*	230.65	15.19	.58
Net Plankton "Out"**	41.58	-6.45	-.05
Diver Gill net	39.55	6.29	.22
Methyl Orange Alkalinity "Out"**	18.48	-4.30	-.46
Dissolved Oxygen Surface "In"*	5.01	-2.24	-.12
Zone II	4.81	-2.19	-.10
Floating Gill net	3.91	2.00	-.01

*measurements taken when nets were placed into the water (mean time 1000 hrs)

** measurements taken when nets were removed from the water (mean time 1430 hrs)

ones measured and others are apparently involved in influencing cyprinid distribution in Klamath Lake.

Distribution of rainbow trout

Only one rainbow trout was taken during the summer months (July, August and September) outside of Zone III and that fish was taken in a spring area along the eastern shore of Zone II. However, along the northern marshy shoreline of Zone III (North Shore Marsh area), fishermen troll lures throughout the summer months. According to Gerlach (1964, 1965) 1.4 and 0.9 trout per angler were caught in this area during the summers of 1964 and 1965 respectively. In this study fish were caught in this area by trolling, and with gillnets set in the shallow (4 to 5 feet deep) water. Trolling and 108 net sets in the other two zones failed to catch any trout during these summer months. But by the middle of October trout began to appear in nets and sport catch of other zones. Angling at this time is done almost entirely from the banks. Fishermen first appear along the eastern shore (Barclay Springs area) and by the middle of November trout can be taken in all three zones, including Wocus Bay. Trout are available to fishermen from the banks until about May of the following spring, then seem to disappear from all zones except Zone III.

The pattern of distribution of rainbow trout along the marshy shoreline follows closely the pattern observed in Figure 32 for the rocky shoreline except that trout did not appear in the Zone III rock shoreline net catch until November. The North Marsh area was the only area to produce trout during the July sampling season and as previously mentioned is the only area in which they are available to fishermen through the summer. The December catch data show that trout were

[1]On the basis of a cut-off of an entering Student's T value of $\pm$ 2.00 as suggested by Dr. Scott Overton.

scattered throughout the lake with most fish taken along Hanks Marsh (Figure 33).

Limited numbers of fish caught prevent the drawing of definite conclusions about the rainbow trout caught in the midlake region, however, in Zone III six trout were caught for the two sampling periods (four in August) compared with one for Zone II. Indicating again, as in the marsh and rock shoreline data, that trout are found in the northern end of the lake during the summer.

The Upper Klamath Lake Trout Fishery.

In spite of algal blooms, high pH, and temperatures of 70°F or higher, rainbow trout maintain themselves in Upper Klamath and Agency lakes and are the object of a year-around fishery. Because the trout require water of a higher quality than the other species in the lake and are extremely mobile, some attention to the trout fishery should aid in drawing conclusions on the water quality from a seasonal standpoint.

Observations, a voluntary creel census, and interviews of anglers and fishery biologists of the Oregon State Game Commission all indicate a seasonal variation in the distribution of trout. This variation is in part due to spawning migration and in part due to changes in water quality. During the winter - from November to April - trout appear to occur in most sections of the lake and are taken by anglers in the southern two-thirds, the area open to angling. During April and May, fishing success diminishes in the southern and eastern sections and becomes better along the west shore.

By June, trout are caught almost exclusively in the northern third of Upper Klamath Lake and Agency lake, and in July and August successful fishing is confined to Agency Lake and a limited area near the shore of Upper Klamath extending from the mouth of Williamson River on the eastern shore to Odessa Creek on the western shore. The incoming waters of Wood and Williamson rivers, Crystal Creek and Harriman Springs appear to influence the summer distribution of trout.

The voluntary creel census covered the period of August 1 to September 5, 1966 when fish appeared to be congregated in the northern sections of the lakes. Cards requesting data on the angling effort, number and size of fish caught and locations of catches were distributed to resort owners.

In some instances the cards were filled out by the resort owners as the anglers returned after fishing, but many anglers cooperated by supplying the requested information. The 82 cards returned came mostly from successful anglers and, judging from boat counts of 7 to 10 on weekdays and 10 to 30 on weekend days, may represent 15 to 20 percent of the effort.

About 70 percent of the fish reported were from 15 to 25 inches long. About 7 percent were longer than 25 inches and over 5 pounds. The catch per hour per angler was 0.19 fish, which compares with a 12-year average of 0.23 fish calculated from data in the Oregon State Game Commission Annual Fishery Reports. The most significant data obtained by the census were the locations of catches, which all appeared to be in the areas near shore under the influence of tributaries at the northern ends of both Upper Klamath and Agency lakes.

Distribution of yellow perch by habitat.

A possible explanation for the complete absence of yellow perch from the July sampling period is that hoop nets were not utilized for sampling until the beginning of the second sampling period. Yellow perch apparently spend the early spring in the marsh area of the northern part of the lake and are first susceptible to sampling in Zone III. They then move south into Zone II with relatively few yellow perch ever reaching Zone I, the few caught in this area were all small (4-6"). The yellow perch taken by nets in Zone II in all months were taken along the eastern shore in areas two and four of that zone (Figure 34).

Yellow perch are taken by fishermen mainly in Zone III, in Pelican Bay and the marsh creeks: Crystal, Recreation and Odessa. Occasionally they are taken from the "canals" around the edge of Hanks Marsh in Zone II. The yellow perch are taken at these places from about the middle of July through September and usually have left these areas by the middle of October, according to fishermen and resort owners.

The marsh shoreline distribution of yellow perch tends to indicate a possible movement to the marsh area in the late fall. Figure 35 shows that 57.7% of the three month's catch was taken in December and that North Shore and Hanks marshes contribute 70.4% of the seasons catch.

Yellow perch were not taken in the month of August in either zone, however, during the September sampling period five individuals were caught; four of these in Zone III. Yellow perch appear to favor the shoreline areas and possibly, even though the lake is shallow, do not venture far from shore.

Distribution of brown bullheads by habitat.

The spatial distribution of the brown bullhead (Figures 36 and 37) shows that 67.7% of the marsh shoreline catch was taken in the North Shore Marsh area, 19.3% in Hanks Marsh, 12.6% in Shoalwater Marsh and 0.4% in Wocus Marsh. Thus, most of the catch seems to be associated with the size of marsh area sampled. The lengths of the marsh shorelines are as follows: North Marsh, 5 miles; Hanks Marsh, 4 miles; Wocus and Shoalwater, 2 miles each. The latter two were characterized by foul water conditions which prevailed into late September.

Although brown bullheads were caught in the midlake area in Zone III during the month of August, most evidence shows that the brown bullhead may prefer the shoreline. The set of nets in August may have intercepted a school of fish "passing through" the area.

Distribution of Sculpins by habitat

The sculpins seemed to be rather evenly distributed throughout the season except for Zone I in November when the catch was almost triple that of the other two zones (Figure 38). The July catch should not be considered as a representative sample of the sculpin population because hoopnets were not employed during that time, and more than 90% of the sculpins were captured in hoopnets.

Only 19 sculpins were caught along the marsh shoreline with Hanks Marsh contributing ten of these fish in the last two sampling periods. A possible reflection on the water quality is indicated by the fact that sculpins were not caught in Wocus Bay.

Sculpins were caught almost equally in both midlake sampling areas of Zone II and Zone III in the month of August (Figure 39). However, sculpins were taken only in Zone III during the September sampling period.

Food Habits of Fishes

Rainbow trout

Because of the stomach contents of gillnetted fish were usually in an advanced state of digestion, and because rainbow trout were seldom taken in seine hauls, only fish taken by angling were used for food analysis. Tendipedids, usually pupae, occurred most frequently and often represented the largest mass. Second in importance were the sculpins, Cottus princeps and C. tenuis. Other groups of importance were leeches (Dina and Glossophonia), dragonflies, damselflies and caddisflies.

Other fishes (Table 28)

Juvenile yellow perch fed mainly upon zooplankton and small insects. The adults added snails and fish to the diet.

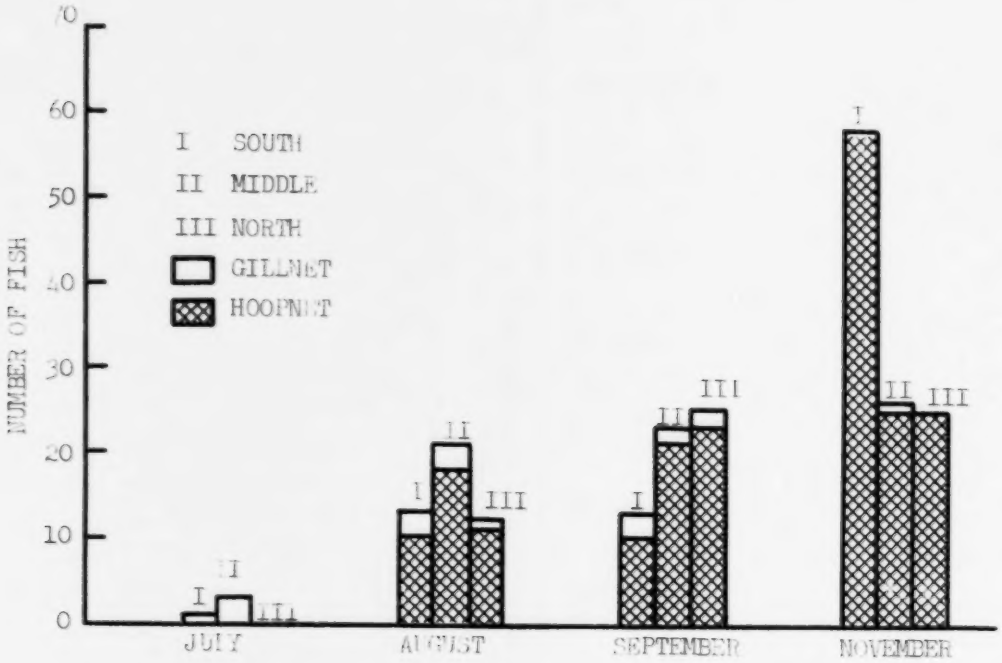

Fig. 38 . The rock shoreline distribution of sculpins (Cottus sp.) Upper Klamath Lake, Ore. 1965.

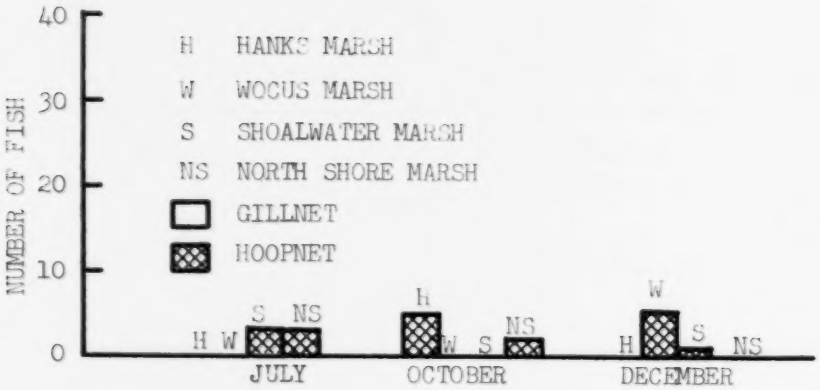

Fig. 39 . The marsh shoreline distribution of sculpins (Cottus sp.) Upper Klamath Lake, Ore. 1965

TABLE 28. Summarized results of stomach analysis indicating per cent occurrence of different types of food organisms.

	number of stomachs observed	number with food in stomach	number-empty stomachs but full intestines	percent with empty stomachs	Algae and Detritus	Rotifera	Copepoda	Cladocera	Daphnia	Chydorus	Amphipoda	Isopoda	Insecta	Hirudinea	Gastropoda	fish	unidentified
					occurrence of organism in stomach or intestine / number of stomachs or intestines with food X 100												
Yellow Perch	63	35	-	44			11	6			11		23		14	69	
Blue Chub	39	15	11	62	38			4	42				27		4	8	4
Tui Chub	34	9	7	74	62	6		6	25	12			37	12	6		6
Suckers	19	11	7	42	39		56	17	33	56			6	6			
Cottus klamathensis	16	16	-	0	31		19		62	6	19	6	69	6			25
Cottus sp.	10	8	-	20	75		12		50	25			100				12

Small blue chubs and tui chubs ate zooplankton and tendipedids. The few adults that contained food when examined had fed upon Cladodera and Copepoda, except for large blue chubs, which occasionally contained leeches.

Sculpins less than two inches long ate zooplankton as well as benthic invertebrates. Cottus over three inches long fed on small benthos, including midges, but ate larger insects such as Aeshna and Limnophilua in addition. Cottus tenuis contained more benthic algae and detritus than the other species. Table 29 shows the food of C. klamathenis which had taken up residence in experimental trays.

Suckers, regardless of size, usually had eaten benthic ostracods, cladocerans and copepods along with considerable detritus.

Live Box Experiments with Rainbow Trout

During the summer of 1966 three experiments were conducted to compare the ability of hatchery-reared rainbow trout fingerlings to survive conditions in Upper Klamath Lake at Rocky Point, a station relatively free of algae, and at Pelican Marina, near the extreme southern end, a station with abundant algae. Fish were obtained from the Oregon State Game Commission trout hatchery near Fort Klamath and transported as rapidly as possible to the stations, where they were placed into live boxes constructed of hardware cloth of 1/8" mesh over a wooden frame. The boxes were 3' on each side.

The first experiment began June 29 and was terminated July 8. Of 50 fish 50 to 75 mm long held at Pelican Marina, 34 died, whereas only 6 of 50 died at Rocky Point. During the period, observed temperatures at Pelican Marina ranged from 59.8 to 64.3°F. Observed pH ranged from 9.1 to 9.7. Temperature and pH were not recorded at Rocky Point.

The second experiment begain July 28 and extended through August 18, and

TABLE XXIX. Stomach Contents of Cottus klamathensis from Experimental Trays, Expressed as Average Number of Food Organism per Stomach.

Length in inches	Freq.	Tendi-pedidae	Tricop-tera	Ephemer-optera	Odo-nata	Cope-poda	Clado-cera	Amphi-poda	Iso-poda	Hiru-dinea
to 1 7/8	3	15.3				2.0	2.7			
2-2 7/8	14	7.3		0.4		0.4	2.0	0.3	2.7	0.3
3-3 7/8	9	8.1	0.2		0.2		0.1			0.1
4-4 7/8	1	8.0	1.0		1.0					

included 52 fish 67-85 mm long at each station. By August 8, 15 fish had died at each station. On August 12 all remaining test animals at Pelican Marina died under the influence of rather severe conditions. The temperature reached 72°F, the pH 9.6, and the dissolved oxygen at the surface fell to 5.6 ppm. Fish at Pelican Marine were infected with a fungus which may have contributed to the mortality.

By August 18 all but three of the fish held at Rocky Point were dead, but a spillage of gasoline at the site of the live-box was thought to be partially the cause.

In the third experiment, 50 fish ranging from 78 to 100 mm long were utilized at each station. The experiment was initiated on September 12 and terminated September 12. No fish died at Rocky Point but 43 succumbed by the third day at Pelican Marine (Table 30).

TABLE XXX. SURVIVAL OF LIVE-BOXED FISH AT PELICAN MARINA AND ROCKY POINT, UPPER KLAMATH LAKE.

Date	Number of Dead Fish		Surface pH		Surface Temperature		Surface D.O.		Inches of Plankton	
	Pelican Marina	Rocky Point	Pel.	M.R. Pt.	Pel.	M.R. Pt.	Pel.	M.R. Pt.	Pel.	M.R. Pt.
9/2	0	0	9.6	9.4	70	54	12.2	6.0	5	$<\frac{1}{2}$
9/5	43	0	9.6	9.4	68	54	7.4	7.4	4	$<\frac{1}{2}$
9/8	43	0	9.6	9.4	65	54	9.2	7.2	4	$<\frac{1}{2}$
9/11	43	0	9.6	9.4	64	53	8.8	7.4	4	$<\frac{1}{2}$
9/12	43	0	9.4	9.4	63	53	8.6	7.6	4	$<\frac{1}{2}$

Although both stations show pH valves which are rather high for the well-being of trout, the environment at Rocky Point, which typifies some of the habitats in the north section of the lake, appeared to be more suited to their requirements. This corroborates observations of angling effort and success as well as the results of the netting program.

Discussion

Outstanding features of Upper Klamath and Agency lakes include the following:

1. large expanses of shallow water exposed to strong winds causing circulation of almost the entire water mass during summer.

2. large expanses of finely-divided bottom materials which can be resuspended by the strong water circulation, thus making nutrients available to the water mass.

Miller and Tash (1967) point out that the upper 1 inch of sediments contain over 31,000 tons of phosphorus and over 70,000 tons of nitrogen in various forms. The active resuspension of the sediments shown in the present study indicates a possible mechanism which can provide algae with an abundance of nutrients almost daily throughout the summer.

Although water quality during much of the fall, winter and spring is such that trout, yellow perch and bullheads can and do inhabit most of the lake, onset of warm water and algae blooms during the summer appear to limit the distribution of the game and pan fishes to marsh areas and lake sections with incoming fresh water. Some usual characteristics of the water during bloom conditions are temperatures from 60° to 74°F , pH from 9.0 to 10.0 and dissolved oxygen fluctuating from about 5 ppm to 17 ppm. These conditions apparently have little effect upon the distribution of the sculpins, Cottus klamathensis and C. princeps; the blue chub, Gila bicolor; the tui chub, Siphateles bicolor; or certain of the suckers, but, as noted, do restrict the non-native yellow perch and brown bullhead, and the more sensitive rainbow trout.

The tremendous potential of Upper Klamath Lake for the production of fish is being realized mainly in the great abundance of chubs. The trout population is held to the number that can be accommodated during the summer in water of suitable quality. As there seems to be little chance of altering water quality, short of extensive deepening by dredging (Miller and Tash, 1967), eventual utilization of the productive capacity of the lake will result either from development of an economic use for the presently abundant species or from the introduction of some desirable species which can withstand the high summer pH and other conditions that accompany the blooms of bluegreen algae.

Many aspects of the limnology and biology of Upper Klamath Lake remain to be investigated. These include hydromechanics and the quantification of nutrient transfer from resuspended sediments; the ecology of the vast oligochaete - leech community in the soft bottom materials; and the physiological adaptation of three species of Cottus and of the rainbow trout to high pH.

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